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Preface

This work was performed in support of the “ADL Common Framework” task sponsored by the Under Secretary of Defense for Personnel and Readiness, Readiness and Training Directorate under the general direction of Dr. Robert Wisher (OUSD/P&R). It partially fulfills the objectives of this task to use the Advanced Distributed Learning (ADL) prototypes and other appropriate sources to develop an “engineering of instruction” that links specific instructional design alternatives to specific instructional outcomes and to assist in the cost and effectiveness assessment of ADL prototypes, including assistance in the design of assessment experiments, collection of assessment data, and documentation of findings.

The author gratefully acknowledges those who reviewed and provided comments on this document.

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Executive Summary

The sense of presence, “being there,” is a real phenomenon. The literature contains many anecdotal accounts of how users have reacted to a virtual scene in instinctual ways that suggest they believe, at least for a short time, that virtual events are real. Yet, much remains unknown. Does a strong sense of presence cause users to engage mental models and cognitive processes that they have already developed in a real environment? Will behavior learned in a virtual world transfer to a corresponding real scenario? These questions remain unanswered. This document reviews what experimental results reveal about the potential relationship some interface characteristics and the sense of presence.

The findings of 127 experiments that have examined the potential relationship between the sense of presence and over 60 interface characteristics are reviewed. In particular, distinctions are made between cases where (1) experiments that can be treated as having been replicated, (2) dissimilar experiments, and (3) isolated experiments have examined a particular interface characteristic. The interface characteristics are grouped under the topics audio display, avatars and agents, interaction, navigation, self-representation, user movement, visual detail, visual display, and (virtual) world characteristics.

Two or more replicated experiments consistently found an advantage for the use of spatialized audio, when users navigated by walking-in-place instead of via use of a 3-mouse or joystick, for the use of a Cave display over a desktop-monitor display, the use of a foreground field-of-view (FOV) restriction over a background FOV restriction, higher update rates, increased levels of audio/visual presentations, and increased levels of scene detail. Replicated experiments consistently found no difference in reported presence for different levels of self-representation body fidelity, for use of a head-mounted display (HMD) and a desktop monitor, and when the number of audio sources differed. The only case where an initial experiment and its replication found inconsistent results occurred when experimenters examined different levels of scene realism. The findings of replicated experiments were supported by consistent findings from dissimilar experiments for all interface characteristics except body fidelity and scene detail. The number of audio sources was the only interface characteristic not examined in additional, dissimilar experiments.

Although not replications, two or more experiments found consistent results for avatar and agent behavioral realism and interaction, level of interaction with the virtual world, use of haptic force feedback, use of texture mapping and texture mapping quality, and visual display FOV and use of stereopsis.

In many cases, the interfaces, virtual worlds, and experimental tasks that have been used in experiments are not representative of likely practical uses of virtual environment technology. This was for good reasons, usually to try and avoid factors that might confound results. So, while past research has provided some indications of interface characteristics whose manipulation may increase or decrease a user’s sense of presence, the findings must be applied cautiously.

Also, presence is usually reported in terms of questionnaire scores that only have a relative value for comparing scores when some characteristic has changed. The meaning of a score in absolute terms is unknown. Even though the characteristics of some interface devices will improve with advances in the underlying technologies, rapid near-term improvements are not foreseen. Meanwhile, understanding how the constraints imposed by virtual environment technology may affect presence will continue to be important.

An important point has been made by more than one researcher: When it comes to presence, just adding “more textures, more resolution, or more …” does not necessarily lead to continual increases in presence.

Instead, a consistent level of realism has to be presented since mismatches in realism seem to cause a conflict that impedes users' sense of presence. In addition, there may be a plateau effect, beyond which it is not cost effective to reach for higher levels of presence, although there are no data on this yet.

1. Introduction

The sense of presence, "being there," is a real phenomenon. The literature contains many anecdotal accounts of how users have reacted to a virtual scene in instinctual ways that suggest they believe, at least for a short time, that virtual events are real. Quite recently, Schuemie et al. (2005) found that some participants were unable to complete an experimental scenario because of the extreme fear they experienced in a virtual world. Yet, much remains unknown. Does a strong sense of presence cause users to engage mental models and cognitive processes they have already developed in a real environment? Will behavior learned in a virtual world transfer to a corresponding real scenario? These questions remain unanswered. This document reviews what experimental results reveal about the potential relationships between some interface characteristics and the sense of presence.

For the discussions here, *spatial presence* is loosely defined as the subjective experience of being in a place or environment, even when one is physically situated in another place or environment. *Co-presence*, then, is the experience of being with another person (actual or computer generated) in a place or environment such that one has access to that person and, conversely, that person has access to oneself. This is different from *social presence*, which goes a step further to address social psychological ideas of personal interaction and implies some awareness of a collocated person's intelligence and intentions.

The purpose of this document is twofold: (1) to provide guidance about interface characteristics that have a good probability of manipulating presence and (2) to give an idea of the scope of experimentation that has been performed. This should facilitate the identification of critical gaps where future research can make the most difference.

Information was collected on experimental work that looked at the potential relationships between interface, personal, and task characteristics and all forms of presence, between task performance measures and presence, and between the different types of presence measures themselves. Experiments were identified from technical journals, conference proceedings, the presence Web site at http://www.presence-research.org, the work of researchers known to the author, and the author's own work. Only those experiments that employed a computer-generated virtual world and analyzed data using an analysis of variance (ANOVA), *t*-test, or similar formal statistical process were included. This resulted in the identification of 206 experiments. This document discusses only those experiments that examined the relationship between interface characteristics and spatial presence (hereafter termed "presence")—127 of the total number. The remaining experiments are covered in another work (see Youngblut (2006)).[1]

Researchers have investigated the relationship between the sense of presence in virtual worlds and over 60 interface characteristics. Figure 1 lists these characteristics. It is not possible to review the results of all the experiments that have considered the potential relationships between interface characteristics and the sense of presence. Instead, the approach taken is to cover those experiments that have been replicated (more or less) and other experiments that have consistent findings for particular characteristics. This is not meant to minimize the importance of nonreplicated experiments that have used good experimental practices. Those experiments can provide direction for system developers working with systems highly similar to the one(s) used in a particular study and may also provide insight into differences that can be

[1] This earlier work discusses 174 experiments.

Audio display:	Aural rendering quality		▲	Sound rotation, velocity		▲
	HRTF		▲	Spatialized audio	■	●
	Sound rotation, direction		▲			
Avatars & Agents:	Agency		○	Relation to user		▲
	Behavioral realism		●	Role, interacting		●
	Form realism		○	Role, passive		●
Interaction:	Audio interaction aid		▲	Latency, end-to-end		▲
	Collision detection, audio		▲	Latency, visual		▲
	Collision detection, haptic		▲	Level of		●
	Collision detection, tactile		▲	Moving between worlds		▲
	Collision detection, visual		▲	Number of		▲
	Haptic force feedback		●	Passive haptics		○
Navigation:	Control of		○▲	Navigation method	■	●▲
	Device		▲			
Self-representation:	Fidelity of body	■	○	Fidelity of hand		○
User movement:	Cross-modal illusions		▲	Seated or standing		▲
	Head movement, bending		▲	Vection		○
	Hand reaching		▲			
Visual detail:	Color		▲	Scene realism	□	●
	Dynamic shadows		○	Texture mapping, use of		●▲
	Rendering quality		○	Texture mapping, quality		●
Visual display:	Device, Cave-HMD-monitor	■	●	Frame rate		▲
	Device, HMD-monitor	■	○	Resolution		▲
	Device, HMD-p/screen-monitor		○	Stereopsis		●
	Device, proj screen-monitor		●	Tracking, face		○
	Device, other		▲	Tracking, head		○
	Field of view		●▲	Update rate	■	●
	Foreground occlusion	■	●			
World characteristics:	Audio cues		○▲	Olfactory cues		▲
	Audio sources, nature of		▲	Presentation quality	■	●
	Audio sources, number of	■		Scene detail	■	●[2]
	Manipulation, presence		▲	Speed of user movement		▲
	Manipulation, social presence		▲	Tactile cues		○

Key:

■ Replicated experiments with consistent findings
□ Replicated experiments with inconsistent findings
▲ Single experiment
● Other experiment(s) with consistent findings
○ Other experiment(s) with inconsistent findings

Figure 1. Interface Characteristics Examined

expected under other circumstances. However, more confidence can be placed in results that are confirmed in replicated experiments. Experiments that have found similar results using a range of interface devices, virtual worlds, experimental tasks, and participant populations may indicate that some of their results can be generalized; however, there are no guarantees. There are bound to be exceptions over time, with a new experiment finding a different relationship for some characteristic. Such exceptions need not invalidate the usefulness of prior work. In some cases, these exceptions may help to define the circumstances under which a particular finding does and does not apply.

Before looking at experimental results, a few words of warning are appropriate. There are hazards in comparing findings across experiments. Most researchers have used questionnaires to assess presence, and these questionnaires differ widely in orientation and scope. The experiments have employed a wide range of virtual worlds. Some were highly detailed representations of real environments, while others presented a small number of objects in an abstract setting. Some virtual worlds were viewed immersively, and

[2] A set of experiments with a consistent finding different from that of replicated experiments.

others were viewed using a large projection screen or a desktop monitor. The levels and modes of supported interaction and the devices used to achieve interaction varied. There were also important differences in experimental protocols, including, for example, participant characteristics and whether presence data were collected while a participant was still in a virtual world or after he had completed that stage of an experiment. Some of the experiments were primarily designed to examine other issues, and presence data were not fully reported. All these differences mean that some minimal knowledge about each experiment is necessary to interpret its results correctly. (Appendix A includes short summaries for each of the full set of 206 experiments.) Finally, although some experimental data show a statistically significant relationship between a particular interface characteristic and the sense of presence, no data establish whether any relationship is a causal one.

Without going into details, Section 2 attempts a broad characterization of the different presence measures that are mentioned in this document. Section 3 provides descriptions of the experiments that are treated as replications. Section 4 identifies remaining experiments in each interface category but only describes those experiments that found consistent results. Section 5 provides some conclusions about what has been learned through all this work.

In this document, when cited papers and reports discuss more than one experiment, the reference to a particular experiment is distinguished, for example, as Snow (1996 (1)) or Snow (1996 (2)).

2. Presence Measures

Most of the experiments used self-report questionnaires to assess the sense of presence experienced by experimental participants. The most widely used questionnaire is one developed by Witmer and Singer at the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI), Orlando, Florida, and is usually referred to as the Witmer-Singer Presence Questionnaire (PQ). This questionnaire was designed to address issues of the immersion provided by the interface to a virtual world and a user's involvement. It consists of 32 items, organized into 6 subscales: Involved/Control, Natural, Interface Quality, Auditory, Haptic, and Resolution. The next most commonly used questionnaire is the Slater-Usoh-Steed (SUS) Questionnaire, which was developed by researchers at University College London (UCL), United Kingdom. The SUS Questionnaire usually consists of six questions based on (1) the sense of "being there" in a virtual world as compared with being in a place in the real world, (2) the extent to which there are times when the virtual world became the dominant reality, and (3) the extent to which a user remembers the virtual world as a place visited rather than one seen in computer-generated images. Some of the other questionnaires are based on the SUS Questionnaire or the Witmer-Singer PQ or have taken items from both. The focus of these other questionnaires can be indicated by their position on a scale with the Witmer-Singer PQ and SUS Questionnaire as poles, as shown in Figure 2.

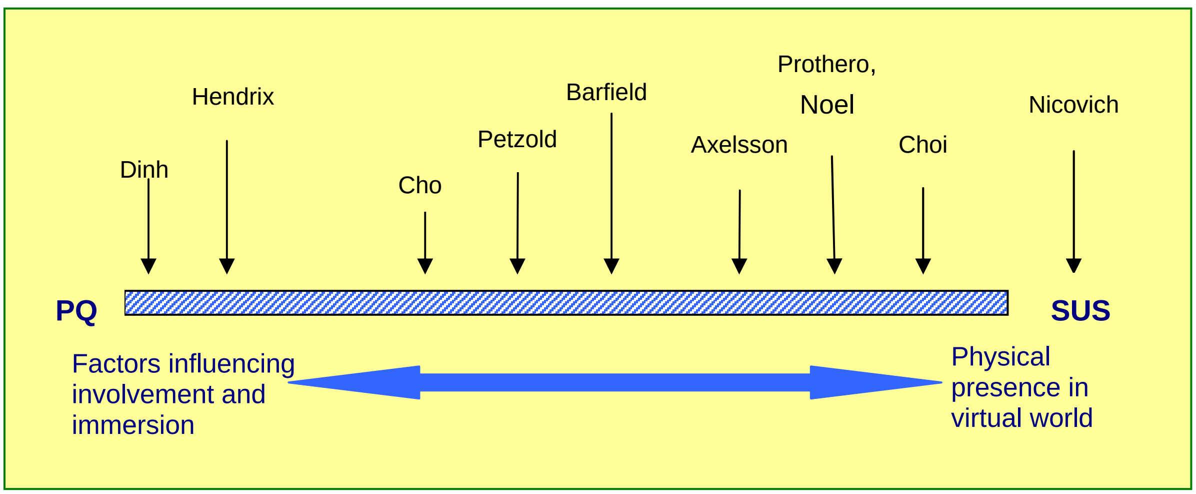

Figure 2. Mapping Other Questionnaires against the Witmer-Singer PQ and SUS Questionnaire

The 14-item Igroup Presence Questionnaire (IPQ) was developed by the Igroup project consortium in Germany. This questionnaire is based on the belief that presence develops from the construction of a spatial-functional mental model of a virtual world and queries users' sense of spatial presence, involvement, and reality in a virtual world. The Independent Television Commission-Sense of Presence Inventory (ITC-SOPI) from Goldsmiths College (University of London), United Kingdom, focuses more on the physical sense of presence and is intended for use with a variety of media, not just virtual environments (VEs). It consists of 44 items grouped into 4 subscales: Sense of Physical Space, Engagement, Ecological Validity, and Negative Effects. Another questionnaire developed in Europe is the Measures, Effects, Conditions-Spatial Presence Questionnaire (MEC-SPQ). In the MEC-SPQ, spatial presence is one of four scales that cover process factors, and it has its own subscales (Self Location and Possible Actions). The remaining three scales address cognitive states and actions, and trait-like personality characteristics. The

Swedish User-Viewer Presence Questionnaire (SVUP) is another questionnaire that focuses on a physical sense of presence. Its full form consists of 150 items that query a user's ability to interact with a virtual world, his awareness of external factors, his enjoyment, and his level of simulation sickness, in addition to asking about the sense of presence. To date, experiments have used only a subset of these items. More details about all the aforementioned questionnaires can be found at http://www.presence-research.org/Questionnaires.html.

The final questionnaire used in the experiments discussed here is the UCL Questionnaire. This is an extended version of the SUS Questionnaire, with 13 items grouped into Reported Presence, Reported Behavioral Presence, and Reported Ease of Locomotion subscales.

Some other types of presence measures are mentioned. Two methods are based on magnitude estimation, a measurement method that has been used in human-related research for many years. For this method, a user is presented with a series of stimuli and asked to assign a number to each stimulus based on his subjective impression of its intensity. Snow (1996) uses a form of free-modulus magnitude estimation that allows the user to assign any appropriate value to the first stimulus and assign numbers to successive stimuli with respect to the first. The method of paired comparison, used by Welch et al. (1996), asks a participant to make a comparison between stimuli, rather than comparing them to some modulus. Participants are asked to provide a rating of the size of the perceived difference between the stimuli. There are also single-item rating scales where a user rates his sense of presence numerically, usually on a scale from 1 to 100.

The only other type of presence measure mentioned is one of several behavioral measures that have been used by the researchers at UCL. In this instance, the participants' *behavioral match and acclimatization* was used as an indicator of presence. Usoh et al. (1996) observed experimental participants to determine whether their behavior in the virtual world was similar to what could be expected in the real world in a similar scenario. They observed (1) whether participants who were familiar with the real-world environment depicted in a virtual world behaved differently from participants who were not familiar with that environment and (2) whether people who were not familiar with the environment could learn something about it from their virtual experience.

3. Interface Characteristics With Consistent Results in Replicated Experiments

There are several cases where researchers have repeated experiments with only minor changes. These replications provide some of the best data on the relationship between a particular interface characteristic and the sense of presence. Figure 3 identifies the interface characteristics that have been addressed in replicated experiments are identified.

Audio display:	Spatialized audio
Navigation:	Navigation method
Self-representation:	Fidelity of body
Visual details:	Scene realism
Visual display:	Device, Cave-HMD-monitor
	Device, HMD-monitor
	Foreground occlusion
	Update rate
World characteristics:	Audio sources, number of
	Presentation quality
	Scene detail

Figure 3. Interface Characteristics Examined in Replicated Experiments

3.1 Audio Display

Researchers have investigated the relationship that might exist between presence and a range of characteristics related to the generation and delivery of audio cues. Among these characteristics, only the use of spatialized audio cues has been examined in a replicated experiment.

Spatialized Audio

Hendrix and Barfield (1996a) hypothesized that using spatialized audio would provide sufficient auditory cues to cause a user to externalize a sound source, resulting in a greater sense of presence and realism. They conducted two experiments to investigate this. Spatialized sounds were generated using an audio spatializer card and delivered over orthodynamic headphones. The actual sounds were a live, continuous broadcast from a progressive light rock radio station and a repeated, discrete recording of a monetary exchange with a vending machine. These sounds were not correlated with any participant activities in the virtual world used. The experiments were conducted in a 10 × 10 m virtual room that had a checkerboard patterned floor and objects such as tables and chairs, a bookshelf, a soda machine, a photocopier machine, and paintings. The virtual room was viewed on a 6 × 8 ft rear projection screen, and participants used shutter glasses to achieve stereo vision. Participants navigated around several different versions of the same virtual room, each time remaining long enough to become familiar with the room. Subsequently, participants completed a questionnaire that had been made available previously.

One experiment compared spatialized environmental sounds against a condition with no sounds (see Hendrix and Barfield (1996a (1))). The second experiment compared spatialized and nonspatialized sounds (see Hendrix and Barfield (1996a (2))). These two experiments used presence questionnaires of slightly different length that shared a common set of questions. In both experiments, participants gave significantly higher presence scores for conditions that included spatialized audio. For both experiments, Hendrix and Barfield also noted that the addition of spatialized sound did not influence participants' ratings of the realism of the virtual worlds. The data did, however, show that higher presence scores were given when a participant found the virtual world to be more realistic and interactive and when the sounds seemed to be more localized to a specific location. They suggested that the lack of a direct relationship between the use of spatialized audio and realism may have been a consequence of the sounds having no

meaning in the context of participant activities or a result of participants focusing on the visual aspects of the virtual rooms.

Section 4.1 describes two additional experiments that had similar findings to this second experiment.

3.2 Navigation

Naturalistic navigation through large virtual worlds has always posed a problem. Without a large open area and a large-area tracker, navigating is difficult in any area except a small virtual room where a user can move normally. Considerable effort has been invested in developing special locomotion devices, such as an omni-directional treadmill, and novel software-supported interaction techniques and navigation aids. One of the most conceptually simple approaches is to have the user direct his movement through a virtual world by walking-in-place. Sensors capture this action and feed the results to a neural net, which can be used to change the visual scene to reflect the user moving in the direction of his gaze. Activities such as climbing steps and crawling in a virtual world still require additional input (usually provided by gestures), but this approach precludes the need for expensive equipment that can pose safety hazards.

Navigation Method

The researchers at UCL have investigated whether walking-in-place was related to higher levels of presence than those that occurred when a user navigated by using a hand-held device. The first experiment (see Slater et al. (1995a)), compared walking-in-place and the use of a three-dimensional (3D) mouse for navigation. Participants used a stereoscopic head-mounted display (HMD) to view the virtual world and were represented in the virtual world as a simple, block-like avatar that was mapped to participant movements by head and hand tracking. The experimental task was to pick up an object in a corridor and take it into a room where a narrow ledge surrounded a 6-m chasm. The object had to be placed on a chair on the far side of the chasm from where participants entered the room. For participants who had a strong association with their virtual body, the researchers reported that those who navigated by walking-in-place gave significantly higher SUS Questionnaire scores than participants who used the 3D mouse. These self-reports of presence were supported by behavioral data showing that participants who walked-in-place were statistically less likely to walk out over the representation of the chasm.

An extension to this experiment was conducted to determine whether the results held given advances in hardware and software technology (see Usoh et al. (1999)). Large-area tracking was used, allowing the comparison of walking-in-place with actual walking and with the use of a modified joystick. Also, a more detailed and realistic avatar was used. The walking-in-place results were the same. Participants who had a strong association with their virtual self-representation gave significantly higher scores than those who used the joystick. As expected, participants in the real walking condition reported the most presence.

3.3 Self-representation

The form realism and behavioral realism used to represent other people or virtual characters in a virtual world has been investigated in several experiments, but little attention has been paid to how the fidelity of a user's self-representation may be related to his sense of presence.

Fidelity of body

Slater, Usoh, and their colleagues, in their work with navigation methods at UCL, found a significant positive correlation between a participant's reported association with his virtual body and his sense of presence. Two experiments by Singer et al. at ARI have provided more insight into this relationship. These researchers wanted to understand the possible effects that a body model might have when used to represent soldiers in Individual Combatant Simulation (ICS). One experiment contrasted the use of a simple, full-body representation and that of a virtual pointer (see Singer et al. (1998)). The full-body self-avatar was linked to a user's movements using trackers on the head, shoulders, feet, right arm, and right hand. Alternatively, a pointer was mapped to the user's right hand. Wearing an HMD, experimental

participants searched for briefcases placed around a typically furnished virtual office. They navigated through the area using a custom hand-held wand. As each briefcase was found, the participant pressed a button on the wand, and the briefcase disappeared. As captured by the Witmer-Singer PQ, presence data did not distinguish between the two forms of self-representation. Singer and his colleagues hypothesized that the absence of any relationship between self-representation and the sense of presence was because the visuals presented by the HMD effectively cut off the participants' views of their lower body. (Performance measures based on the number of collisions, time taken, and number of targets acquired also failed to distinguish between the two experimental conditions.)

These researchers conducted a second experiment, which they termed a replication (see Allen and Singer (2001)), to investigate this relationship further. This time, participants performed a slightly different task. In this second experiment, participants had to complete a guided navigation task and then search for floor locations in order and drop markers on them. In one condition, instead of a virtual pointer, the participant's hand was mapped to a virtual hand. In addition, the experiment included several real-world conditions, using a mockup HMD (constructed from plastic welders' goggles with cardboard cutouts and masks) that reduced resolution and luminance to match the visual characteristics of the HMD. These additional conditions provided an expanded horizontal visual field, an expanded lower visual field, and a normal visual field condition. Using the Witmer-Singer PQ, results for the virtual-world conditions were similar to those of the first experiment. Participants' self-representation showed no significant relationship with overall presence scores, although a significant difference was found for the Natural subscale. For this subscale, participants who had the disembodied virtual hand representation gave significantly higher scores than participants who had the full-body self-avatar, perhaps because those in the latter group had to look down at an unnaturally sharp angle to see and use their full virtual representation. In comparison with the real-world conditions that matched the HMD's resolution and luminance, participants rated presence (on all subscales except Natural) as significantly higher in the virtual world. The Witmer-Singer PQ subscales indicated that participants found the virtual world easier to control and less interfering, which probably made it easier for participants to examine objects. Allen and Singer questioned whether this preference for the virtual world was the result of participants' anchoring biases (e.g., being unaccustomed to viewing the real environment through a masking helmet). There were also significant differences in Witmer-Singer PQ scores among the real-world conditions for all but the Involved/Control subscale. Additional analyses found a significant positive correlation between presence and field of view (FOV) in these conditions.

There are no supporting data.

3.4 Visual Detail

This section concerns interface characteristics that are constrained by the available computation resources rather than the visual display device. As such, *Scene realism* addresses the extent to which a virtual world includes the types of sensory cues found in the real world. *Scene realism* is the only interface characteristic in this group that has been examined in a replicated experiment (and the only replication discussed in this document where experimental results were inconsistent).

Scene realism

Achieving a high degree of scene realism can be computationally expensive. Some types of realism (e.g., simulating weather effects) can require massive computations that are still challenging to perform in real time. As with many other interface characteristics, the question becomes "How much is enough?"

The only experiments that have manipulated scene realism and that can be considered replications varied fish movement and fish skin deformation in a simple underwater scene. These two experiments were performed at the Pohang University of Science and Technology (POSTECH), South Korea, by researchers who were trying to combine the results of previous work that had investigated the relationship between some individual interface characteristics and the sense of presence. One experiment considered six visual

elements (stereoscopic viewing, participant control of navigation, geometry, texture mapping, object motion, and object self-motion) (see Cho et al. (2003)). Two levels of object motion were achieved by having fish move through the scene or remain stationary. For object self-motion, one experimental condition provided increased realism by rotating and translating vertices in the fish geometry to simulate skin deformations. Using a 50-in. screen, participants viewed 30 versions of the virtual world for 90 sec each. Using a 4-item questionnaire, they gave significantly higher presence and visual realism ratings for conditions where the fish moved. The additional realism introduced by the use of skin deformation, however, was not related to any significant difference in presence scores. Presence scores did show significant interactions between fish movement and between texture and the number of polygons used. Based on the results of the statistical analyses and, in particular, the relative weights of each manipulation and the interactions, Cho et al. concluded that the extent to which manipulation of model details can increase the compelling nature of a virtual world is limited.

In the second experiment, the only difference between the high and low levels of realism was the use of skin deformations. In both experimental conditions, fish randomly changed their orientation and moving velocity, while checking their position to ensure that they remained within a pre-established base position. (FOV was also manipulated, as described in Section 4.8.) This time, each version of the virtual world was viewed on a panoramic display constructed of 1 to 3 desktop monitors. Using an 8-item version of the Witmer-Singer PQ, the difference between the high- and low-realism conditions was reflected in a significant difference in presence scores. It is uncertain why these experiments had different results when the realism of fish skin was increased. The inconsistency may be attributable to differences in the presence questionnaires used. Also, the fact that fewer characteristics were manipulated in the second experiment could have resulted in the change in skin appearance assuming greater importance in the second experiment. Shim and Kim (2001), based on their cost model, concluded that the computational cost of adding skin deformation to every fish was too high for the amount that presence increased.

Three other experiments were consistent in finding no relationship between scene realism and the sense of presence (see Section 4.9).

3.5 Visual Display

Vision is the primary sense used to build a user's sensation of being present in a virtual world. Fifty experiments have considered the relationship that various visual display characteristics may have with the sense of presence. Twenty-four of these experiments focused on visual display devices ranging from a 6-sided Cave[3] system to the screen of a Personal Digital Assistant (PDA). Two series of replications found a consistent result for the relationship between display device and the sense of presence. Additional replicated experiments have examined the use of foreground versus background occlusions on a display screen, and a range of update rates also had consistent findings. These experiments also had consistent results.

Display device, Cave-HMD-monitor

Researchers from Chalmers University of Technology in Sweden and Oxford University and UCL in the United Kingdom worked together in experiments that focused on how pairs of participants could work together over a distance using two different types of VEs. The virtual world used in these experiments presented eight cubes with one of six colors on each side. The challenge for experimental participants was to assemble the cubes so that each side of the resulting structure displayed a single color. In the work reported by Axelsson et al. (2001) and Wideström et al. (2000), one participant was in a 5-sided Cave and used shutter glasses to achieve stereo vision, and his partner viewed the virtual world on a desktop

[3] Cave™ is a trademark of the University of Illinois at Chicago. Use of the term "Cave" in this document refers to any display system that uses three or more projection screens arranged to form a room.

monitor. Using a 2-item questionnaire and an additional 1-item rating of the sense of the virtual world as a place visited, the Cave participants gave significantly higher presence scores and a significantly higher rating of the virtual world as a place visited. (There were no significant differences in reported co-presence or in the amount of communication activity between partners. While participants felt they contributed equally to the experimental task overall, they indicated that they felt the Cave participants contributed significantly more to moving the cubes.)

In an additional experiment (see Schroeder et al. (2001)), some participant pairs used 5- and 4-sided Caves, and other pairs used a 5-sided Cave and desktop monitor. As before, Cave participants gave significantly higher presence scores and place-visited rating than desktop-monitor participants, immersed participants were felt to have contributed more to moving the cubes, and there was no difference in the amount of communication initiated by Cave and desktop-monitor participants. The new experimental condition allowed comparing (1) the outcomes across 5- and 4-sided Caves and (2) the sense of presence of partners who used the same or dissimilar displays. For the first of these, there was no significant difference between the presence scores from the 5- and 4-sided Cave participants. The place-visited data, however, showed that pairs who both used Cave systems gave significantly higher ratings than the immersed participant in a pair that used a Cave and desktop monitor. (A similar distinction was found in the co-presence data.)

A later extension to this work added two more conditions to cover collaborating using a 5-sided Cave and an HMD and collaborating using two desktop monitors (see Heldal et al. (2005)). The findings in this case supported Schroeder's conclusions. Participants who used displays of similar immersiveness (Cave to Cave, HMD to HMD, or monitor to monitor) reported levels of presence similar to those of their partners and, for desktop-monitor participants, the level of presence was significantly lower when their partner used a Cave than when their partner used another desktop monitor. Looking across conditions, participants who used a Cave or an HMD still reported significantly more presence than those who used desktop monitors. The researchers also reported that participants' performance in the immersive display conditions was close to that in a real-environment setting.

Section 4.8 describes an earlier experiment conducted by these researchers—an experiment that had a consistent finding when using a different virtual world and experimental tasks.

Display device, HMD-monitor

Although relatively few multiuser experiments have been reported in the literature, another series of replications that used different types of visual displays also used groups of participants. This series of experiments was conducted as part of the European Collaborative Virtual ENvironments (COVEN) project by researchers from the Swedish Institute of Computer Science (SICS) in Kista, Sweden, and the University of Nottingham and UCL, United Kingdom. The purpose of the 4-year COVEN project was to investigate the feasibility of developing a scalable Collaborative Virtual Environment (CVE). This work included exploring concepts such as presence, co-presence, and collaboration in small-group behavior. Some of the experiments used a virtual world that was a model of the actual laboratory where study took place. It included a room that had sheets of paper displayed around the walls. Each sheet had several words in a column, and each of the words was preceded by a number. The words across all sheets with a common number combined to form a saying. Participants worked in groups of three to solve these word puzzles. In each group, one participant viewed the virtual world using a stereoscopic head-tracked HMD, and the other two participants used desktop monitors.

The first experiment was intended as an exploratory study to generate hypotheses about how participants would behave in such a collaborative task. Each group of participants performed the task in the virtual world first and then in the real world (see Slater et al. (2000b)). In this experiment, the VE systems were connected over a local area network (LAN). A second experiment, where participants collaborated over a wide area network (WAN), was conducted to assess the feasibility of additional research. No data from that study have been published. Two more experiments were conducted using a WAN (see Tromp et al.

(1998 (2)) and Steed et al. (1999)), and there were some differences in response times as compared with the first study. Also, some of the nonnative speaking participants overseas had language problems that probably affected the collaboration. Regardless, in all three experiments, there was no significant difference between the SUS Questionnaire scores given by participants who used the HMD and their confederates who used desktop monitors. (The SUS Questionnaires differed in length across the experiments.) There also was no significant difference between co-presence scores. However, a significant positive correlation found between presence and co-presence in the first two of these experiments was absent in the third experiment.

Other experiments that have compared the use of HMDs and desktop monitors had mixed findings (see Section 4.8).

Foreground occlusion

As part of an investigation into the possible relationship between the visual illusion of self-motion (circular vection) and presence, Prothero et al. (1995a) hypothesized that users in a virtual world form a reference frame. They call the frame that an observer takes to be stationary the "rest frame." This hypothesis predicts that for the same FOV, the sense of presence in a virtual world will be enhanced when the user believes that the FOV restriction is occurring in the foreground. They conducted an experiment to test this hypothesis, using an HMD with 40° × 105° FOV and an eye mask that restricted the foreground occlusion to 40° and the peripheral occlusion to 60°. The participants also viewed the virtual world when a paper mask was placed over the HMD screens (i.e., further away from their eyes). The virtual world used in the experiment was Division's SharkWorld, and participants had to catch sharks using a virtual net that was mapped to the position of their real hand. Prothero and his colleagues found the participants gave significantly different presence scores for each placement of the occlusion. Participants reported higher presence for the foreground eye masking. Prothero et al. (1995a (2)) repeated the experiment using a double-bind design for additional reliability and found the same results. The researchers had problems finding supporting data using a computer-generated electronic mask (again, effectively a background occlusion) but ascribe this to difficulties they encountered with another virtual world that was used.

An additional experiment provides supporting data (see Section 4.8).

Update rate

A fast visual display update rate provides smoother scene movements that are less likely to cause perceptual conflicts that might reduce a user's sense of presence. Barfield and his colleagues performed two experiments designed to determine what update rate was "good enough." The first experiment examined update rates of 25, 20, 15, 10, and 5 Hz. The second compared update rates of 20, 15, and 10 Hz and also looked at the differences in presence that might result from using two different types of devices to navigate through a virtual world (3DOF joystick or 3DOF SpaceBall). Both experiments had participants search through a reconstruction of Stonehenge looking for a rune inscribed on one of the menhirs. The virtual world was presented on a 6 × 8 ft rear projection screen and viewed stereoscopically using shutter glasses. As expected, in the first experiment, Barfield and Hendrix (1995) found that participants gave higher presence ratings for the faster update rates. For an overall presence rating and other questions directly related to presence, scores for 25- and 20-Hz update rates were significantly higher than those given when the virtual world was presented at 10 and 5 Hz update rates. There were no significant differences for two additional questionnaire items related to participants' awareness of the real world or simulation speed. Participants also reported significantly higher perceptions of the fidelity of interaction for 25- and 20-Hz update rates as compared with a 5-Hz update rate. This perceived fidelity of interaction had a significant, positive correlation with presence scores.

The second experiment used a longer version of the presence questionnaire that included items related to the engagement of senses in a virtual world (see Barfield et al. (1998)). Again, participants reported significantly higher presence scores for faster update rates. Looking at the subset of the questionnaire most

like that used in the first experiment, presence scores given for 20- and 15-Hz updates rates were significantly higher than those given for a 10-Hz update rate.

An additional experiment that found supporting data is described in Section 4.8.

3.6 World Characteristics

The set of interface characteristics considered in this section reflect choices that system developers may make, over and above any constraints imposed by interface devices. Replicated experiments have looked the potential relationship between the sense of presence and the number of audio sources, variations in the overall audio/visual presentation quality, and scene detail.

Audio sources, number of

A group of researchers has investigated the auditory illusion of self-motion as part of project called the European Perceptually Oriented Ego-Motion Simulation (POEMS). Based on ideas of ecological acoustics, they expected that the characteristics of a sound source would be important in inducing vection. In particular, they investigated the role of a rotating sound field, using several concurrent sound sources, and differences in acoustic rendering quality. Most of this research used an aural reconstruction of a marketplace in Tübingen, Germany.

Two experiments by the POEMS' researchers used the same three still-sound sources (a bus on idle, a small fountain, and a barking dog), with binaural simulations of a virtual listener standing in one location and rotating a certain number of laps. The acoustic simulations were rendered offline in CATT-Acoustic v8 using Walkthrough Convolver and presented to a participant over circumaural headphones. The experimental trials were conducted in a semi-anechoic room, and the participant was seated on an electronically controlled turntable. Both experiments compared presence data after participants heard three concurrent sound sources and when they heard a single sound source. One experiment asked participants to provide a 1-item rating of presence (see Väljamae et al. (2004)), and the other used a magnitude estimation measure of presence (see Larsson et al. (2004)). The experimental results were consistent in finding that participants' reported level of presence when they heard three concurrent audio sources was not significantly different from the reported level of presence they gave after hearing a single audio source.

No other experiments have considered the potential relationship between the number of audio sources and a user's sense of presence.

Presentation quality

Nuñez and Blake have reported on two experiments that shared several similarities in examining the effect of presentation quality on the sense of presence. In both experiments, participants explored a virtual ancient monastery under one of two audio/visual conditions. These conditions used the same visual display resolution ($640 \times 480 \times 16$), but one condition included textures, radiosity, and spatialized audio cues, whereas the second condition used flat shaded polygons and no sound. Participants were given the task of looking for 20 boxes placed throughout the building. One experiment (Nuñez and Blake, 2003a) had a third condition: a text-based representation of the monastery that was supported by low-resolution ($280 \times 100 \times 8$) still images. In the second experiment (Nuñez and Blake, 2003b), participants performed two trials: one in the monastery and the second in a virtual contemporary hospital. The second experiment also sought to investigate whether developing a sense of presence is a constructive process that depends on more than sensory input. To gain some insight into this question, Nuñez and Blake gave participants related or unrelated priming materials to read prior to their virtual experience.

These experiments used both the Witmer-Singer PQ and the SUS Questionnaire to collect presence data. In both experiments, the two questionnaire scores distinguished between the two audio/visual conditions, with significantly higher presence scores given for the condition with textures, radiosity, and spatialized

sound. In the first experiment, however, only the Witmer-Singer PQ distinguished between the low-presentation quality audio/visual condition and the text-based version. The SUS Questionnaire and Witmer-Singer PQ are based on different views of presence, so this lack of consistency between their results is not too surprising. Nuñez and Blake stressed that the noteworthy issue was the difference in the mean presence scores for the high audio/visual and text-based conditions. They calculated an average per-item difference of 16% of the Witmer-Singer PQ and 8% of the SUS Questionnaire—a difference that was statistically significant but of small magnitude. On this basis, they said that a VE designer can expect the sense of presence to be lower in a text-based world than in a comparable graphics-based world—but only by less than 20%. However, in the absence of a better understanding of the influence presence may have on task behavior and other outcomes, the importance of this 20% can only be empirically determined on a case-by-case basis. (Priming had a significant interaction with audio/visual quality. Participants who received related priming material and were exposed to the higher level of presentation quality reported significantly more presence on both the SUS Questionnaire and the Witmer-Singer PQ than the other participants.)

Another experiment with a consistent finding for presentation quality is described in Section 4.9.

Scene detail

Welch et al. (1996 (1)) considered scene detail in the context of a driving task. Participants worked in pairs and took turns as the driver or passenger in a virtual car. The driver controlled the car using a steering wheel and foot-operated accelerator and brake pedals. His task was to drive the car as quickly and smoothly as possible through a lap on a winding road. The task for the passenger was to count the number of oncoming cars. Two virtual worlds were used. The high-detail world had a blue sky, a hilly road surface and surround, and a green background, with red farmhouses, oncoming cars, and guard posts. In the low-detail world, which showed only a black sky and background, the road surfaces were flat, and no peripheral objects such as farmhouses and oncoming cars were present. All participants viewed the virtual worlds on a desktop monitor using shutter glasses to provide stereoscopic vision. Presence was assessed using the paired comparison method: participants indicated in which of the worlds they felt more physically located and rated the difference between the two virtual worlds. Participants gave significantly higher presence ratings for the more detailed virtual world (and for the more interactive driving task, as described in Section 4.3).

A second experiment also investigated whether the sense of presence was reduced when an additional 1.5-sec delay was imposed on visual feedback (usually 200–220 msec). The same equipment, virtual worlds, and driving task were used (see Welch (1996 (2)). As before, participants indicated significantly higher levels of presence for the increased scene detail. (Visual delay also had a significant effect, with participants giving higher presence ratings for the shorter delay.)

Other experiments that manipulated the level of scene detail in considerably more complex worlds did not find this difference in presence scores.

4. Interface Characteristics With a Consistent Finding Across Experiments

Consistent results across dissimilar experiments can be an indication of the importance of a particular interface characteristic and the generalizability of its relationship with presence across different circumstances. Of course, this cannot be stated with any degree of certainty. There is always the possibility that an additional experiment will bring previous results into question. On the other hand, conflicting findings may be the result of legitimate differences in experimental protocols (e.g., use of different presence measures or participants being drawn from different populations). Only experiments with consistent findings can be described.

Figure 4 identifies the categories of interface characteristics for which experiments have found consistent results. Citations are given to papers that discuss experiments where the findings across experiments are inconsistent. Experiments that are unique in addressing some interface characteristic are similarly identified. Because of the broad categorization scheme used in this document, some interface characteristics have both a set of experiments with (in)consistent findings and one or more unique experiments in which each investigated a different aspect of the same interface characteristic.

Audio display:	Spatialized audio
Avatars & agents:	Behavioral realism
	Role, interacting
	Role, passive
Interaction:	Haptic force feedback
	Level of
Navigation:	Method
Visual detail:	Scene realism
	Texture mapping, use of
	Texture mapping, quality
Visual display:	Device, Cave-HMD-monitor
	Device, projection-screen monitor
	Field of view
	Foreground occlusion
	Stereopsis
	Update rate
World characteristics:	Presentation quality
	Scene detail

Figure 4. Characteristics With Consistent Results Across Dissimilar Experiments

The symbols used in Figure 1 are repeated in the Section 4 category headings to provide a quick guide as to whether relevant experiments are treated as having a consistent finding, inconsistent findings, or are unique in how they manipulated a particular interface characteristic.

4.1 Audio Display

Several experiments have investigated audio characteristics that can affect the quality of audio cues used in a virtual world. Most of this work has been performed as part of the European project called POEMS. The goal of this project was to investigate how sensory illusions in a virtual world could be used to create both a sense of presence and of user motion. The interface characteristics examined were aural rendering quality, the use of individualized head-related transfer functions (HRTFs), the rotation of sound sources, and the spatialization of audio cues. This latter characteristic is the only interface characteristic in this group whose relationship with presence has been examined in more than a single experiment.

Aural rendering quality ▲ (see Larsson et al. (2004))

HRTF ▲ (see Väljamae et al. (2004))

Source rotation, direction and velocity ▲ (see Riecke et al. (2004a))

Spatialized audio

As mentioned in Section 3.1, a pair of 1996 experiments by Hendrix and Barfield found that participants reported a higher level of presence when they experienced spatialized audio cues. The work of the POEMS' researchers provides mixed support for this finding (see Riecke et al. (2005)). This more recent work differed in major ways from that of Hendrix and Barfield. Instead of an indoor room that participants viewed using a head-tracked HMD and navigated by means of standard mouse placed on a table in front of them, the Riecke et al. participants were seated in front of a curved, rotating visual display of an outdoor marketplace and did not navigate through the virtual space. The sound cues were generated by a different sound system and delivered using headphones with different characteristics. The sense of presence itself was reported using a different questionnaire. One similarity between the earlier work and this later work was that the audio cues in both cases were matched to the visual scene (e.g., the sounds of a soda machine for Hendrix and Barfield and that of a fountain for Riecke et al.). Despite all the differences in experimental conditions, Riecke et al. also found that participants gave significantly higher presence ratings for spatialized sounds than for conditions that used nonspatialized audio cues. However, the Riecke et al. results differed in that participants' ratings of presence did not distinguish between nonspatialized audio and no audio conditions. This may have been a result of the fact that the presence scores were low for all three conditions and the differences in scores across conditions were small. (For vection, spatialized audio cues increased the convincingness rating and build-up time. Although these were statistically significant differences across the experimental conditions, again, the differences were small. These findings were taken as evidence that cross-modal consistency is important in virtual worlds.)

Bormann (2005), as part of her investigation into the potential relationship between presence and task performance, also investigated the use of spatialized audio cues. In this experiment, the sounds were either fully spatialized or directional but nonattentuated; therefore, there was less difference between the audio conditions than those that occurred in the experiments just mentioned. Participants played two games. The first game, called *WhoDo Mansion*, was originally developed for experiments conducted as part of the COVEN project (see Normand (1999)). A participant started this game by clicking on a radio in a central area. This caused the radio to begin playing and a first domino to be released so that the participant could start searching for and marking dominos in a prescribed order. In this game, the radio was a passive source since it had no direct contribution to the task. The second game, called *Hyperball*, was played in a virtual world that consisted of 19 hexagonal rooms. Only the central room had any objects: two pedestals on which a ball and a radio were placed. Again, the game started when the radio was clicked on. Depending on the experimental condition, either the ball or the radio would assume the role of "hyperball." When the participant clicked on the hyperball, it moved to one of the other rooms where the participant had to find the hyperball and click on it again. This continued for a total of 12 moves. In this game, the audio source was an active one when the radio was the hyperball and the noise from radio provided information about its position. Bormann reported that the relationship between spatialization of audio cues and the sense of presence depended on the presence measure used. SUS Questionnaire scores were significantly different across the two experimental conditions (fully spatialized or directional but nonattentuated audio), but there was no significant difference in Witmer-Singer PQ scores. Witmer-Singer PQ scores did, however, have a significant positive correlation with the participants' ratings of their own performance. Objective performance scores did not correlate with the scores of either presence questionnaire.

4.2 Avatars and Agents

Virtual characters can represent an actual human engaged in some capacity with a virtual world or be driven by a computer program. The convention is to call the former representations "avatars" and to call the computer-driven representations "agents." The influence that agent and avatar characteristics may have on presence has become a popular area of research in recent years. Most of the work has focused on how form realism and behavioral realism could be related to the sense of co-presence and social presence.

In the following, *Agency* refers to whether a virtual character is controlled by a human or a computer or is perceived as such by a user. The topic *Relation to user* concerns whether the user was previously familiar with the person controlling an avatar.

Agency ○ (see Eastin and Griffiths (2006)), (see Nowak and Biocca (2003)), (see Ravaja et al. (2006))

Behavioral realism ●

Two different groups have examined the potential relationship between behavioral realism and the sense of presence. UCL researchers have examined a range of agent behaviors but have only reported presence data for an experiment that manipulated agent responsiveness (see Garau (2003b (1))). The virtual world used for this experiment depicted a library with five agents seated around a table. Four levels of agent responsiveness were used. In the least responsive condition, the agents remained in an unmoving position, as if they were reading books. For the next level of responsiveness, the agents were animated and exhibited behaviors such as fidgeting and turning pages. In the third level of responsiveness, agents would change their posture and engage in gaze behavior if approached by the participant. For the fourth (and highest) level of responsiveness, the first agent approached would speak to the participant (using what would seem to be a foreign language). A 4-sided Cave display system was used for the experiment, and the participants wore shutter glasses and navigated by means of a hand-held 3D mouse. The experimental task was simply to observe the virtual surroundings. Garau found that agent responsiveness was not related to any significant difference in SUS Questionnaire scores. There was a significant correlation with computer usage such that participants who had computer usage reported significantly higher presence scores for the talking condition. There was also a significant positive correlation between presence scores and participants reports of co-presence.

The Department of Communication at Stanford University has conducted extensive research into users' responses to avatars and agents in CVEs. These researchers have recently reported on a longitudinal study that examined nonverbal behavior, task performance on verbal tasks, and ratings of presence, co-presence, simulator sickness, and entitativity[4] (see Bailenson and Yee (2006)). In 15 trials over a 10-week period, participants worked in groups of 3 to solve 3 types of world puzzles in a CVE. Participants used HMDs and headphones to interact with the virtual world. When entering the CVE, a participant saw his team members sitting around a table. Behavioral realism was manipulated according to the researchers' transformed social interaction (TSI) paradigm. This research paradigm examines the disjoint between human characteristics and behaviors that exist in physical space and the characteristics and behaviors that are rendered to others in a CVE. The experiment used three levels of TSI. In the normal TSI condition, a participant saw his team members wearing their own faces and gesturing veridically. At the TSI level beneath this, called face similarity, a participant saw his own face superimposed on the others' faces, but these other participants still gestured veridically. For the third TSI level, called the mimic condition, each participant saw the other two wearing the correct faces, but his teammates were shown mimicking his own head movements at a 4-sec lag. Again, the different levels of behavioral realism were not related to any significant difference in presence questionnaire scores. (The experimental manipulation also had no significant effect on Entativity and co-presence scores. There was a nonsignificant negative correlation between trial day and presence scores.)

Form realism ○ (see Gerhard et al. (2001a)), (see Nowak and Biocca (2003)), (see Tromp et al. (1998 (2))), (see Vinayagamoorthy et al. (2004))

Relation to user ▲ (see Ravaja et al. (2006))

Role, interacting ●

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[4] Entativity refers to group cohesiveness. "A tightly-knit, well-functioning group would be high in entativity, while a noncohesive collection of disjoint individuals would be low." Bailenson and Yee (2006), p. 11.

Five experiments have investigated whether embodied agents that interact with, and in some way provide information to, a user can cause that user to experience a higher degree of presence. All the experiments found that the use of the agent was associated with a significant increase in the sense of presence reported by participants, regardless of how compelling each experience was or whether the virtual world was viewed immersively.

Researchers from the Fraunhofer-Institut für Software- und Systemtechnik (Fraunhofer Institute for Software and Systems), Germany, and Leeds Metropolitan University and the University of Bradford, United Kingdom, conducted an experiment intended to help them understand the relevance of user self-representation and co-presence in CVEs. A virtual art gallery with three exhibition rooms was used. This gallery was populated with 45 images of artwork taken from the British National Artists Register Axis database. In one experimental condition, the gallery also held a prototype, embodied conversational agent, called Art-Fairy, that had been developed using advanced agent technology (see Gerhard et al. (2005)). This agent used speech and gestures to communicate and had a limited knowledge of the gallery space and current exhibition of artworks. The experimental task required a participant to select one favorite piece of artwork in each exhibition room. The experiment was fully Web based, so participants viewed the virtual world on a desktop monitor. (The participants were selected randomly from among those who subscribed to the Axis database.) Presence data were collected as part of a 20-item post-session questionnaire. Participants who were accompanied by the conversational agent reported significantly higher levels of presence than participants who explored the museum alone.

Another experiment was designed to investigate the effects of immersion and coaching by a virtual agent on the motivation and sense of presence of participants cycling a stationary home exercise bicycle. Ijsselsteijn et al. (2004a) used a computer-controlled female agent to play the role of a fitness trainer. Every minute, the virtual coach could encourage a participant to do better. Based on the participant's heart rate, the virtual coach would tell the participant that he was doing great or to slow down a little. The researchers varied both the level of participant interaction (see Section 4.3) and the inclusion of the virtual coach. All the participants were seated on a stationary racing cycle mounted on a training system with variable resistance, and they viewed a virtual world on a wall-mounted screen. Participants who experienced the virtual coach gave significantly higher scores for the ITC-SOPI Spatial Presence subscale and significantly lower scores on the Negative Effects subscale.

A third experiment was motivated by the fact that simulator sickness is more prevalent for passengers in VEs and motion simulators than for users who control vehicle motion (see Lin et al. (2004)). Researchers at the University of Washington's Human Interface Technology Laboratory (HITLab), in their investigation of this problem, have developed a procedure called a Virtual Guiding Avatar (VGA). This procedure, combined with self-motion prediction cues and an independent visual background, is intended to reduce simulator sickness. They conducted an experiment to test this procedure using a driving simulator that includes a full-size car positioned in front of a panoramic display composed of three 230 × 175 cm projection screens. The virtual world presented on these screens was University of Illinois' Crayoland, a cartoon virtual world containing a cabin, pond, flowerbeds, and a forest. Participants viewed Crayoland using shutter glasses for stereo vision. The VGA, in the form of an abstract airplane, was seen hovering in front of the car, facing the forward direction, so that its movements provided participants with a prediction of coming motion as they were driven on a quasi-circular trajectory that included left and right turns and forward and rearward translations. Experimental conditions used a VGA that provided non-earth-fixed reference with turn cues, earth-fixed reference with turn cues, earth-fixed reference without turn cues, or no prediction cues. Presence data were collected using an Engagement, Enjoyment, and Immersion (E^2I) scale that included a 4-item presence subscale, a 1-item structure of memory test score, and a 5-item enjoyment scale. Participants gave significantly higher presence scores for a VGA that provided non-earth-fixed reference with turn cues or earth-fixed reference with turn cues than for a no-prediction-cue VGA. (Participants' simulation sickness questionnaire scores were significantly lower for the two VGA conditions that included turn cues.)

As part of research designed to test the use of free-modulus magnitude estimation as a measure of perceived presence in VEs and build empirical models of presence, Snow (1996) conducted a series of three experiments. One of these experiments examined the presence or absence of a second user (along with the number of interactions possible in a VE and the level of detail). The experimental task consisted of five part-tasks: two vision tasks, a manipulation task, a locomotion task, and a reaction-time choice task. All these tasks were performed in a simple virtual world with a checkerboard floor, walls with narrow vertical stripes, ceilings with horizontal light panels, and 3-ft-wide corridors. Participants had no self-representation. Participants viewed the virtual world using a monoscopic HMD with head tracking. They navigated through the virtual world by means of a 3D controller positioned under their left hand, and a two-dimensional (2D) mouse under their right hand was used for object interaction. These devices were placed on a rotating platform in front of the participant. In the condition where a second user was present, the researcher was represented as a human-like avatar who accompanied the participant, talking about the events in the virtual world, each other's movements, and occasionally bumping into the participant and opening doors for him. As measured using the magnitude estimation measure, participants who were accompanied in the virtual world reported a significantly higher sense of presence than those participants who were not accompanied (see Snow (1996 (3))).

To ascertain the potential influence that an advertising agent may have on the effectiveness of an advertising Web site, researchers at the Michigan State University's Media Interface and Network Design (M.I.N.D.) Lab investigated several hypotheses (see Choi et al. (2001)). They anticipated that a Web advertisement that included an agent would generate more spatial and social presence and that the advertisement would be more effective (in terms of favorable attitudes to the advertisement and to the product, a higher intention to purchase the product, a higher intention to revisit the site). They also sought to determine whether a favorable attitude toward the advertisement would promote favorability to the product and, thus, purchase intention and whether presence and social presence would mediate the effect of the agent to influence advertisement attitudes. The Web site that was used as the experimental medium provided various information and images in a 3D format. In one experimental condition, the advertising agent provided messages using speech and nonverbal cues. The same messages were given in textual format in the second experimental condition. Presence items were included as part of a larger questionnaire. Participants who experienced the advertising agent had significantly higher spatial and social presence scores than other participants. (The agent was also associated with significantly more favorable attitudes and behavioral intentions. Based on a formal path analysis, Choi et al. (2001) also found a positive relationship between presence and the measures of advertising effectiveness.))

Role, passive ●

Three additional experiments where a virtual character had no interaction with participants also had a consistent finding: the mere presence of an agent was not related to a significant difference in participants' ratings of their sense of "being in" a virtual world.

Schubert et al. (2000 (1)) represented an agent by footprints that appeared crossing a corridor after a door had opened. The experiment was conducted in a simple virtual world consisting of a hallway in an administration building. A participant stood at an intersection and looked into four corridors, each of which had numerous doors. Across the wall, several plates were visible, and the experimental task was to count these plates. In the condition that included agents, doors opened and closed from time to time, and two comic-strip-like shoes came out of the doors, walked across the hall, and entered other rooms. Participants viewed this virtual world using an HMD with head tracking. Navigation in the virtual world was limited by natural walking in a 5-m diameter circle. Presence data collected using the IPQ showed no significant difference between the experimental conditions.

The provision of an agent was one of the factors manipulated by the researchers at UCL in an experiment that examined how several characteristics might influence the sense of presence (see Slater et al. (1994)). Participants played a game based on a mixture of *Excalibur* and *Beauty and the Beast*. Each of a series of

environments contained a hidden set of swords embedded in stone. Once such a set was found, the participant had to identify the one sword that could be moved, find a nearby well, and drop the sword down the well. The beast was awakened when the correct sword was found. Participants viewed the virtual world using an HMD with head tracking and used a 3D joystick for navigation and for interacting with virtual objects. To assess whether the inclusion of an agent had any relationship with presence, some participants were followed by an agent (who did not otherwise interact with them), and other participants experienced a version of the virtual world where the agent remained standing in one position. Presence was measured using three items on a larger questionnaire. Again, there was no significant difference in participants' presence scores across the two conditions.

Another experiment by the research team at UCL used agents in the form of cardboard cutouts. This research posed two questions: Does an increase in participants' sensory and proprioceptive inputs result in a higher sense of presence? Is there a relationship between the degree of familiarity and adaptation to an environment (acclimatization) and presence? Accordingly, the virtual world used in this experiment was modeled on a laboratory in the Computer Science Department (Room V127) (see Usoh et al. (1996)). It included accurate color and placement of desks, chairs, computers, cabinets, and floor space. Half of the participants were familiar with this room, and the others had never visited it. In one experimental condition, half of the desks in the virtual room had an agent standing by them. As in the previous experiment, participants viewed the virtual world using an HMD with head tracking. However, this time, they navigated using a mouse and interacted with virtual objects via their virtual hand. A participant's task was to move through the virtual room and switch on any six of the computers, being automatically transported back to the starting position after each computer was switched on. Next, they had to go back and identify the computers previously turned on by touching those computers (without being transported after each touch). Again, presence was measured by three items on a longer questionnaire. Usoh et al. also observed whether the participants followed socially conditioned behaviors and conventions while in the virtual world. Neither measure revealed a significant difference across the experimental conditions.

Although these experiments had a consistent finding, the influence that more human-like agents would have had on the results is uncertain. Also, there are no data that indicate whether an agent with behaviors, though still maintaining its independence of a user, might influence the user's sense of presence.

4.3 Interaction

None of the experiments that have investigated interaction characteristics have been replicated, and few have examined the relationship between the same aspect of an interface characteristic and the sense of presence.

Audio interaction aid ▲ (see Nordahl (2005 (2))), (see Witmer and Kline (1998 (2)))

Collision detection, audio ▲ (see Durlach et al. (2005)), (see Petzold et al. (2004)), (see Snow (1996 (2)))

Collision detection, haptic ▲ (see Lee et al. (2004a))

Collision detection, tactile ▲ (see Durlach et al. (2005))

Collision detection, visual ▲ (see Durlach et al. (2005)), (see Uno and Slater (1997))

Haptic force feedback ●

One interaction area where the sense of presence has been considered by several groups of researchers is the use of haptic feedback for collision detection. Four experiments have used SensAble Technologies' PHANTOM haptic devices to examine the effect that providing force feedback to a fingertip can have on performance in manipulation tasks. In the earliest experiment (see Sallnäs et al. (2000)), pairs of participants collaborated in five different tasks. Four of these tasks involved building patterns out of a collection of eight cubes, and the other task was to navigate through a pattern constructed of cubes. The standard

PHANTOM device provides only a single-point interaction. To lift a cube, participants had to collaborate in pushing up on a cube from different sides, or a participant could press a cube against one of the walls and push upward. The cubes had simulated form, mass, damping, and surface friction. Force feedback was also provided for the walls and for each partner, with a slight vibration used to distinguish between touching a cube and touching or holding onto a partner. The virtual scene was viewed on desktop monitors, and partners conversed over telephone headsets. Despite the limited nature of the haptic cues, participants who performed the experimental tasks with force feedback gave significantly higher Witmer-Singer PQ scores than those who performed tasks with no such cues. (Use of haptic force feedback also resulted in significantly shorter task performance times and significantly higher ratings of perceived task performance but had no relationship with social presence scores.)

Sallnäs (2004 (6)) used a different virtual world and experimental task for a second experiment. Participants again worked in pairs, this time in virtual room with two large shelves that had six cubes resting on them and two smaller target shelves. Partners needed to work alternatively. One participant would lift a cube and pass it to his partner, who tapped the target shelf with the cube. The partner then returned the cube to originator, who tapped his shelf with the cube. Task difficulty was adjusted by randomly varying cube size. Again using the Witmer-Singer PQ, Sallnäs found that participants who experienced force feedback gave significantly higher presence scores. (The same participants also reported higher levels of perceived task performance. In this second experiment, however, the use of force feedback was related to significantly higher social presence scores. Perceived performance ratings had a significant correlation with spatial presence scores but not with social presence scores.)

The other two experiments that used the PHANTOM investigated the sense of presence for teleoperation tasks. In one of these, researchers from POSTECH, Korea, and the University of Southern California collaborated in investigating the problem of shared autonomy for controlling a mobile robot. The experiment was designed to determine how force feedback could support visual feedback in aiding participants to direct the speed and rate of turn for a robot with on-board obstacle collision detection. They compared the rendering of environmental and collision-prevention information, environmental information only, and a condition with no feedback. In this instance, the feedback only provided indirect information about the robot's environment and not direct task feedback. Participants practiced a safe navigation task in a virtual world where a virtual robot was represented as a cube (the bounding box of the real robot) and had a top-center-positioned virtual camera, a front-facing virtual laser scanner, and a rear-facing sonar array, all supported by the appropriate simulations. After training with each navigation method in the virtual world, participant performance was tested in the equivalent real environment. The type of forces provided had a significant relationship with presence data collected using a 3-item questionnaire, with more presence reported for the force feedback conditions than for no feedback (see Lee et al. (2004a)). The researchers hypothesized that the indirect haptic cues improved presence because they acted as a local spatial cue for a participant's perception of the space. (The type of force feedback also had a significant relationship with the number of collisions but not with the time to complete a navigation task.)

Petzold et al. (2004) compared the use of force feedback with video and audio feedback in a telepresence system for micro assembly, where the actual assembly was performed by a Bosch SR6 Turboscara robot. In the force feedback condition, 6DOF forces measured by a sensor were fed back to a PHANTOM. Scenes captured by two cameras were displayed on a video monitor, and the visual scene was displayed as a virtual scenario. The researchers' assumptions were that sensory substitution would be more successful when visual and auditive force cues were presented together and that auditive augmentation could especially improve the effect of haptic feedback. The experimental task was a pick-and-place task that involved mounting an hour-wheel onto the corresponding minute-wheel in the clockwork of a wristwatch. Presence data were gathered using a questionnaire. Here, again, the provision of force feedback was associated with a significant increase in reported presence. (Task completion times had a significant negative correlation with presence scores, which may indicate that participants who experienced more presence completed the task quicker.)

Latency, end-to-end ▲ (see Meehan et al. (2003))

Latency, visual ▲ (see Welch et al. (1996 (2)))

Level of ●

Two of the five experiments that investigated the relationship between the level of user interaction and the sense of presence employed driving tasks where participants took the role of either a vehicle driver or a passenger. One of these experiments, by Welch and his colleagues, has already been described in Section 3.6. The second driving experiment was conducted in support of the development of Georgia Tech's Non-expensive Automatic Virtual Environment (NAVE). This system has three 8 × 6 ft screens that can be used alone or in combination. Seay et al. (2001) wanted to determine users' likely experience of presence and simulator sickness under different display and user role configurations. For the experiment, a participant was seated in front of the center screen and took a 10-minute drive in a virtual car, using a joystick as the control device. Using a within-subjects design, participants experienced both controlling the car and a guided navigation scenario. Presence data were collected using the Witmer-Singer PQ. Both these experiments found that participants gave significantly higher presence scores for the more interactive driving task.

Nicovich et al. (2005) also used a vehicle control task in their experiment, but this time the vehicle was a virtual plane. Participants in the high-interaction condition flew a takeoff and landing using Microsoft Flight Simulator 98. The experiment was run on a desktop computer, using that system's monitor and speakers for the visual and audio displays. Participants used a joystick to control the plane. Other participants viewed a recorded video of the same game scenario. Using a 5-item questionnaire, Nicovich et al. found (1) that participants in the more interactive pilot condition reported higher levels of presence and (2) an interaction with gender such that males reported less presence than females in the noninteractive condition and more presence than females in the interactive condition.

Larsson et al. (2001) examined the relationship between interactivity and participants' presence ratings using a different type of virtual scenario. Participants visited a recreation of Orgryte Nya Kyrka in Göteburg, Sweden. A female agent performed "Swanee River" while moving along a predetermined path through the church. Participants in the interactive condition counted the number of windows in the church and searched for four colored balls. When a participant approached a ball, a sentence appeared in the color of the next ball to be found. These participants were also asked to remember the sentences (though their memory was not tested later). They viewed the virtual world using a stereoscopic HMD with head tracking and headphones and used a joystick for navigation. Participants in the noninteractive condition simply visited the church, viewed using a screen, and had headphones for audio input. Four items from the SVUP were used to collect presence data. Again, participants in the interactive condition reported significantly more presence, although the extent to which this result was influenced by the difference in display devices used by the experimental groups is uncertain.

Finally, the experiment by Ijsselsteijn et al. (2004a) that studied the use of a fitness trainer in a home exercise application (see Section 4.2) also manipulated the level of participant interaction. In the highly interactive condition, participants could control their direction and speed of progress using the bicycle's handlebars and pedals. They saw a scenic virtual world where they were on a racing bicycle traveling through the landscape. Participants in the less interactive condition saw an abstract picture of a racetrack from a bird's eye view, with a dot indicating the position of the bicycle. In this less interactive condition, the handlebars and pedals did not affect the participant's position or progress. Based on ITC-SOPI data, participants in the more immersive condition reported significantly higher levels of presence.

Moving between worlds ▲ (see Slater et al. (1994))

Number of ▲ (see Snow (1996 (3)))

Passive haptics ○ (see Durlach et al. (2005)), (see Hoffman et al. (1996)), (see Insko (2001 (2))), (see Lok et al. (2003)), (see Meehan (2001 (2)), (see Viciana-Abad et al. (2005))

4.4 Navigation

Researchers have investigated the relationship between users' sense of presence and their control over their movement through a virtual world, the device used for that navigation, and particular navigation methods. Only in the case of *Navigation method*, specifically, walking-in-place, does additional work support the findings of the replicated experiments discussed in Section 3.2.

Control of ○ (see Bystrom and Barfield (1999), (see Freeman et al. (2005)), (see Ijsselsteijn et al. (2004a)), (see Schubert et al. (2000 (1))), ▲ (see Cho et al. (2003))

Device ▲ (see Barfield et al. (1998)), (see Witmer and Kline (1998 (2)))

Navigation method ●, ▲ (see Razzaque et al. (2002))

Slater and Usoh's finding that participants reported a higher sense of presence when walking-in-place, compared with a less natural navigational approach, is supported with additional data from an experiment performed by another group of researchers. Researchers from the Delft University of Technology and the University of Amsterdam, the Netherlands, were concerned with identifying a practical locomotion method for use with virtual worlds designed for Virtual Reality Exposure Therapy (VRET) (see Schuemie et al. (2005)). The experiment compared walking-in-place, hand-controlled navigation using a hand-held track ball, and gaze-directed steering through head tracking. As in the earlier experiments, participants in the Schuemie et al. experiment used head-tracked HMDs. The virtual world, however, was very different. It included a room designed to determine the controllability of the interaction techniques and another part that contained height situations intended to determine the effect of the locomotion technique on the fear of the users. Participants first had to navigate through the couch- and plant-filled room and then ascend in a virtual elevator to the second area of the virtual world. After leaving the elevator, they found themselves on the roof of a tall building in a city scene. The task in this new environment was to search for boxes that were placed around the area in which participants needed to move close to large vertical drops. Presence data were collected using the IPQ. As reported by Slater et al. (1995a) and Usoh et al. (1999), participants who navigated by walking-in-place reported significant higher levels of presence than those who used a hand-controlled device or an approach based on head tracking. (Using measures based on positioning and the number/magnitude of collisions, Schumie and colleagues found that navigating by walking-in-place was significantly more accurate than either of the other navigation methods.)

4.5 Self-representation

Section 3.3 described two highly similar experiments that found no significant difference between the presence scores given for full-body self-avatars and for a simpler form of self-representation (a virtual pointer or a virtual hand). The only related research had an inconsistent finding. Two other experiments also had inconsistent findings when they manipulated the fidelity with which a participant's hand was represented in a virtual world.

Fidelity of body ○ (see Slater and Usoh (1993a))

Fidelity of hand ○ (see Durlach et al. (2005)), (see Lok et al. (2003))

4.6 User Movement

How physical movements in the real environment might be related to a user's sense of presence has been examined in only a few isolated cases. Slightly more attention had been paid to how the illusion of self-motion might be related to the sense of presence. However, the results of these experiments are difficult to compare since they assessed different attributes of vection.

Cross-modal illusions ▲ (see Biocca et al. (2001))

Head movement, bending ▲ (see Slater et al. (1998))

Hand reaching ▲ (see Slater and Steed (2000a))

Seated or standing ▲ (see Bystrom and Barfield (1996))

Vection ○ (see Olsson et al. (2001)), (see Riecke et al. (2004a))

4.7 Visual Detail

This section concerns interface characteristics that are affected by the availability of computational resources, and advances in technology over the years have changed the importance of some of these. This is particularly true in the case of *Color* and *Texture mapping*.

Color ▲ (see Barfield and Weghorst (1993 (1))), (see Slater et al. (1995c))

Dynamic shadows ○ (see Slater et al. (1995b), (see Mania and Robinson (2004))

Rendering quality ○ (see Cho et al. (2003)), (see Dinh et al. (1999)), (see Snow (1996 (3))), (see Zimmons and Panter (2003))

Scene realism ●

UCL's experiment that investigated whether the inclusion of a passive agent influenced participants' sense of presence also manipulated scene realism by simulating the effects of gravity. In the scenario based on *Excalibur* and *Beauty and the Beast*, when an participant picked up and let go of an object, the object would either fall or hang suspended in space (see Slater et al. (1994)). This manipulation was not related to any significant difference in SUS Questionnaire scores.

Another experiment by the same researchers had the same finding. For this later work (see Slater et al. (1996)), participants had to reproduce a sequence of moves seen in a virtual world on a real tri-dimensional chess board. Some participants saw the virtual chess game suspended in space. For others, the chess board was on a table that was set in a picnic scene in an open field. All participants viewed the virtual world using an HMD with head tracking. Depending on the experimental condition, participants had either an egocentric or exocentric viewpoint. A 3D mouse was used for navigation and object interaction. As in the earlier experiment, presence data were gathered using the SUS Questionnaire.

The third experiment that has considered scene realism was conducted by the researchers at ARI. This experiment was designed to assess the capability of VE technology to aid users' in spatial knowledge acquisition. Singer et al. (1997) used an abstract terrain derived from composite topographical maps and a terrain obtained from a visual database built from a topological map and aerial photographs of an area near the McKenna Military Operations in Urban Terrain (MOUT) site at Ft. Benning (Georgia). Participants used either an HMD with head tracking and walked on a treadmill for navigation or used an HMD without head tracking and navigated using a 6DOF joystick. Both these groups had hand tracking to support pointing activities. A third group of participants served as a control group and used a map instead of either virtual terrain. Presence data captured using the Witmer-Singer PQ did not distinguish between the two VE groups. (Presence scores also did not distinguish between the two types of interfaces. Several performance measures, however, favored the more realistic terrain and the use of an HMD with head tracking and walking on a treadmill.)

Texture mapping, use of ●, ▲ (see Slater (1995c))

The two experiments that investigated how the use or absence of texture mapping might be related to the sense of presence have already been described. The work of Snow (1996) was first mentioned under the topic of *Role, interacting* in Section 4.2. The later experiment conducted by Cho et al. (2003) was described for *Scene realism* in Section 3.4. Both these experiments used relatively simple virtual worlds,

although they differed substantially in the user interface and type of experimental task. Regardless, both Snow and Cho et al. reported that the use of texture maps was associated with significantly higher levels of presence.

Texture mapping, quality ●

Two experiments have addressed the quality of texture mapping. Both experiments, though quite different, found a relationship between texture mapping quality and the reported sense of presence.

Zimmons and Panter (2003) combined texture resolution with variations in lighting quality. Four experimental conditions were rendered using combinations of a high or low texture resolution and a high or low lighting quality. The fifth condition employed only a black and white texture grid. The experimental participants used a stereoscopic HMD with head tracking to view the virtual world. This world showed a pit, and the participant had to drop three balls onto a target in the bottom of the pit. Presence questionnaire scores did not differ significantly across the five experimental conditions. Changes in heart rate were similarly unrelated. (Accuracy in dropping the balls onto the target and the participants' perceptions of the depth of the pit were not related to texture and lighting quality.)

The second experiment manipulated texture quality by using repetitive or nonrepetitive textures. The virtual world consisted of a high street with several secondary streets. Approximately 40 textures were used for shop billboards and store fronts in the nonrepetitive textures condition, whereas only 20 distinct textures were used in the repetitive textures condition. A second experimental factor was the form realism of agents that walked out onto the street. A 4-sided Cave display system was used, and participants wore shutter glasses for stereoscopic viewing. Participants were free to explore once they entered the virtual street. SUS Questionnaire scores and ITC-SOPI scores did not distinguish between the use of nonrepetitive and repetitive texture maps (see Vinayagamoorthy et al. (2004)). There was a significant interaction between texture mapping quality and the form realism of agents such that the condition with the most realistic agent and repetitive texture mapping gave the lowest presence scores.

4.8 Visual Display

The experiments described in Section 3.4 found consistent results when comparing the use of Caves, HMDs, and desktop monitors; the use of HMDs and desktop monitors; foreground and background occlusions; and different update rates. This section describes experiments that found supporting evidence for all but one of these findings. The exception is the use of HMDs and desktop monitors. Additional experiments have had consistent findings when comparing the use of large projection screens and desktop monitors, different FOVs, and stereoscopic or monoscopic viewing.

Display device, Cave-HMD-monitor ●

Axelsson and his colleagues, prior to their series of replications using Cave display systems and desktop monitors (and HMDs in the final experiment), had examined the relationship between visual display devices and presence in an earlier experiment (see Axelsson et al. (1999)). This earlier work used much of the same interface equipment but a different virtual world and task. The virtual world was an open space that contained ball-and-stick molecular models of roughly 1,200 atoms (Myoglobin in the Cave condition and Cytochrome-2 in the desktop-monitor condition). The participants' task was to locate the single iron atom within the molecule, identify the atoms connected to it, and then count the number of carbon rings in the molecule. Participants using the Cave display worked in groups of four to six, while participants using the desktop monitor worked in pairs. As in the later experiments conducted by these researchers, participants used a 2-item presence questionnaire based on the SUS Questionnaire to report their sense of presence. The findings of this experiment were consistent with those of the other experiments. In this experiment, participants gave significantly higher presence scores after using the Cave display than they did after using the desktop monitor. (There was no significant difference between the 1-item co-presence scores given by participants after using each system. For the Cave display, presence scores had a significant positive correlation with co-presence and 1-item collaboration scores but not with communication.

For the desktop monitor, there was no significant correlation between presence scores and any of co-presence, collaboration, and communication scores.)

Two recent additional experiments compared the presence experienced in a Cave with that experienced when using an HMD. The first of these was designed to compare the ability of Cave and high- and low-end HMD systems to distract users from external and unpleasant stimuli (see Dumoulin et al. (2006)). The high-end HMD provided a 60º FOV and 1280 × 1024 resolution, with head tracking and a 6DOF wand for user interaction. The low-end HMD had a 26º FOV and 800 × 600 resolution, with head tracking and a mouse for user interaction. The experimental task was to count yellow objects in a virtual apartment. After the first minute of each trial, an electric sander (90 dB) was heard continuously for the remainder of the trial. Participants reported significantly higher presence after their sessions in the Cave than after using the high-end HMD and significantly more presence after using the high-end HMD than after using the low-end HMD. (While results on the amount of distraction experienced in each system were not significantly different, when asked which system they perceived as more powerful in distracting them from the noise, participants gave the highest ratings to the high-end HMD system.)

The second experiment was designed to assess the effectiveness of VRET using different display systems. All the participants met current Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) criteria for severe acrophobia. Some patients received therapy in a 4-sided Cave, using shutter glasses for stereo vision, and the therapist accompanied the patient into the Cave. Other patients used a stereographic HMD with head tracking and were able to move freely in a $1m^2$ area that was encircled by a railing. The remaining patients—the control group—were taken from a wait list of people who had received no treatment. Four virtual worlds were used in the VRET conditions: a shopping mall with four floors, a fire escape with six floors in open space, a roof garden on a building, and a building site with eight floors. All VRET patients received three treatment sessions consisting of only exposure therapy. Presence and state anxiety data were collected halfway through and at the end of each session. Krijn et al. (2004) reported that the two VRET conditions were equally effective and both were more effective than no treatment. (However, some virtual worlds did not elicit anxiety in several patients, and these patients dropped out of the study.) With regard to presence, Cave patients gave significantly higher IPQ scores than patients who had received therapy using an HMD.

Display device, HMD-monitor ○ (see Mania (2001b)), (see Nichols et al. (2000 (1)), (see Priore et al. (2003)), (see Slater et al. (1996)), (see Slater et al. (1995c)), (see Wiederhold et al. (1998)), (see Youngblut (2004 (3)))

Display device, HMD-projection-screen monitor ○ (see Baños et al. (2004)), (see Nystad and Sebok (2004)), (see Riley and Kaber (1999))

Display device, projection-screen monitor ●

Two experiments have investigated whether participants who used a large projection screen reported more presence than those who used a desktop monitor (see Youngblut 2004 (1) (2)). The same equipment was used in both experiments. A 9.5 × 7.5 ft rear projection screen was used as a 1-sided Cave, with black curtains for the other three walls. Participants who used the projection-screen display navigated through the virtual worlds and interacted with virtual objects using a belt-mounted custom 3D joystick. Interaction was supported with head and hand tracking. A table-mounted joystick was used for participant navigation and interaction in the desktop-monitor condition. Participants had no self-representation in the virtual worlds, although humanoid agents were used to represent other characters. Both experiments used the Witmer-Singer PQ and the SUS Questionnaire to collect presence data.

The first experiment used three virtual worlds from the Institute for Defense Analyses' (IDA) Virtual Cities library. One was a recreation of a warehouse on New York Pier 16, another was an office building in New York City, and the third was Penn Station. All were modeled with sub-meter accuracy for the building architectures and included objects appropriate to each building's purpose. The experimental task

was to learn mission procedures for chemical and biological (chembio) hazard searches in a designated area. All participants began with a study of a written description of the mission procedures. One group of participants then practiced the procedures using the projection-screen system, and another group practiced the procedures using a desktop monitor. A third group—the control group—received no practice. For this experiment only, participants in the projection-screen condition carried a mockup of the chembio detector that responded to the location and strength of hazards modeled in the virtual worlds. Desktop-monitor participants accessed this device using joystick controls. Participants communicated with an off-site team commander using a voice-activated radio. A different virtual world was used for each of three training missions, and the presence questionnaires were completed after each participant had completed his third training mission. Training transfer for all three groups of participants was then tested in a real-world scenario. Analysis of the data revealed no significant differences in the Witmer-Singer PQ scores of participants who trained using the projection screen and those who trained using the desktop monitor. Similarly, no difference was found in the SUS Questionnaire scores. (Participants who practiced mission procedures in the virtual worlds scored significantly higher on performance measures, but there was no significant difference in performance scores between the two VE groups. SUS Questionnaire scores had a significant positive correlation with a subset of performance scores.)

The second experiment used the same group of participants. In this case, the virtual world represented the ground floor of an office building with 12 exterior offices, 4 interior offices, 2 small open areas, and 2 large open areas, one of which contained another office. There were two exterior entrance doors to the building, and two stairwells provided access to the upper floors. The space was empty except for eight objects. These objects were items of furniture, such as a desk, file cabinet, sofa, and snack machine. Six objects were positioned in offices, and the remaining two objects were positioned in the open areas. In one experimental condition, participants viewed the virtual office area on the rear projection screen, whereas participants in a second condition used a desktop monitor. A control group studied the spatial layout using only a paper floor plan. Participants in the VE groups had three exposures to the virtual world on separate days, each time being asked to navigate freely through the office space to build their spatial knowledge of the area. These participants completed the presence questionnaires after the third session. The spatial knowledge of all participants was tested using distance and orientation tests and a room placement test (the latter was repeated 1 week later as a retention test). Again, there were no significant differences in Witmer-Singer PQ or in SUS Questionnaires scores across projection-screen and desktop-monitor participants. (The only significant difference in test scores was found in the accuracy of the initial room placement test: participants in the projection-screen group were significantly more accurate than participants who only studied the paper floor plan. Relationships between performance scores and each of the Witmer-Singer PQ and SUS Questionnaires scores were mixed.)

Display device, other ▲ (see Eastin and Griffiths (2006)), (see Laarni et al. (2005)), (see Lawson (1998)), (see Otto et al. (2005)), (see Rand et al. (2005)), (see Rand et al. (2004 (1)))

Field of view ●, ▲ (see Allen and Singer (2001)), (see Freeman et al. (2005))

It is desirable for the FOV of a visual display to extend across the user's foveal and peripheral vision since these areas play different roles in perception. This is a particularly critical problem for HMDs, where increasing the size of optics often requires tradeoffs against other important characteristics. Eight experiments have examined the relationship between the sense of presence and FOVs, using HMDs, large projection screens, and desktop monitors. Six of these experiments found that participants reported significantly higher levels of presence after using displays with larger FOVs. The remaining two experiments, where no differences in presence scores were found, are treated as a separate consistent group since they both examined smaller FOVs than the other experiments.

Using a Division dVisor HMD, Prothero and Hoffman (1995b) reduced the device's 40° × 105° FOV by including modified tanning goggles. Since the aperture on these goggles was very close to a participant's

eye, the eye mask had a different effect on direct (40°) and peripheral (60°) vision. The experimental task used Division's SharkWorld, where participants had to catch sharks using a net. Prothero and Hoffman found an unexpected gender effect. Only females' reports of presence differed significantly with the FOV, although, as expected, significantly more presence was reported for the larger FOV condition. Also, considering all participants, the difference in the level of presence reported for the viewing conditions was only significant when participants performed the task using the wider FOV first. Prothero and Hoffman suggested that if participants' expectations for the virtual scenario were initially low, they may have been more accepting of a smaller FOV unless they had already experienced a larger one. Based on related work that looked at the effect of foreground and background occlusion (see Section 3.5), the researchers felt that using a background occlusion, such as a mask on the HMD screens, would have resulted in a larger difference in presence scores across the two conditions.

Snow (1996 (1)), as part of his series of experiments described in Section 4.2, used a VR4 HMD and examined changes in presence scores for 48º × 36º, 36º × 27º, and 24º × 18º FOVs. His participants performed part-tasks such as distance estimation and target selection in a virtual world comprised of simple rooms and left- and right-turn corridors. With only 12 participants, although using a within-subjects design, he found a significant difference between reports of presence given for the 48º × 36º and 36º × 27º FOV conditions and that reported for the 24º × 18º FOV condition.

Hendrix and Barfield (1996b (3)) examined FOV in one of a series of three experiments they conducted to investigate the relationship between visual display characteristics and the sense of presence. These researchers manipulated geometric FOV (GFOV), which had the effect of magnifying or minimizing the displayed image and, with a fixed display size, also affected the amount of the virtual world that was seen. The virtual world was a room populated with typical office furniture. Experimental participants viewed this world on a 6 × 8 ft rear projection screen (stereopsis and head tracking were also experimental factors). The participants were asked to navigate the virtual room and become familiar with it. Using a 5-item presence questionnaire, presence scores for the 90º GFOV and 50º GFOV were significantly higher than the scores for the 10º GFOV.

The next three experiments manipulated horizontal FOVs (HFOVs) at the periphery of human vision. The researchers at POSTECH, Korea, used a panoramic display comprised of 3 large-scale TV screens that allowed them to compare participants' presence scores for the 180º, 150º, and 120º FOVs (see Shim and Kim (2001)). Concerned with how different technical characteristics could be manipulated to get the most from a given hardware setup and limited computational resources, this work considered both FOV and the level of realism. Participants viewed a virtual fish tank containing 30 fish that exhibited different levels of behaviors. Shim and Kim found a significant difference between Witmer-Singer PQ scores given for the 180º and 120º FOVs. The level of realism also had a significant relationship with presence scores (see Section 3.4); however, the expected interaction between these experimental factors (i.e., that a larger FOV would enable participants to see the difference in fish behaviors better) was not found.

As part of the development of their E^2I scale for evaluating a user's experience in a virtual world, researchers from the University of Washington's HITLab and Department of Otolaryngology examined whether the scale was sensitive to changes in FOV. This experiment used the Real Drive driving simulator described in Section 4.2. Comparing FOVs of 180º, 140º, 100º, and 60º, they found that participants' scores on the Engagement and Immersion subscales (intended to assess presence) were significantly higher for 180º FOV than for 100º FOV and significantly higher for 100º FOV than for 60º FOV. The lack of a statistical difference between presence for 180º FOV and 140º FOV led these researchers to hypothesize an asymptote effect beyond 140º FOV.

Seay et al. (2001) (see Section 4.3) compared Witmer-Singer PQ scores when participants viewed the single screen (60º FOV) and the 3-screen panoramic display (180º FOV). The researchers reported that presence scores given for the panoramic display were significantly higher than those given for the single screen display,

Two additional experiments had results that differed from those just discussed. Both used projection screens. The focus of the research conducted by Klimmt et al. (2005) was to ascertain the value of secondary task reaction times (STRTs) as an objective measure of presence. These researchers conducted an experiment using a hypertext media, a film media, and a VE media. In the VE conditions, where participants navigated through a virtual museum, the FOV was changed (61º, 20º) to manipulate the sense of presence experienced by participants. There was no significant difference in MEC-SPQ scores or the STRT data. In the other experiment, Sacau et al. (2005) examined the potential relationship between personality factors and presence. These researchers also employed a range of media, and, in this case, a computer game was used for the VE condition. As before, one of the factors that was changed in the VE condition was FOV (60º, 30º). Again, the difference in FOVs was not related to any significant difference in MEC-SPQ scores. Klimmt et al. speculated that the intrusive nature of the visual and auditory probes used for the STRT procedure may have had an unwarranted effect on participants' sense of presence, whereas Sacau et al. felt that the difference between the large and small FOVs may not have been large enough to influence participants' sense of presence. Either or both of those suggestions may be true. These are the only two experiments that used the MEC-SPQ to capture presence data, and the MEC-SPQ might not have been sensitive to this experimental manipulation. As mentioned previously, the different findings from these two experiments may also be a consequence of the smaller sizes of the two FOVs examined in each experiment.

Foreground occlusion ●

The POEM project's research provides supporting data for the findings of Prothero et al. (1995a) that a foreground occlusion was related to an increase in the sense of presence that a user experiences in a virtual world. Like Prothero et al. (see Section 3.5), these researchers' focused on inducing the illusion of self-motion. For this experiment, the virtual stimulus was a photorealistic representation of the marketplace in Tübingen, Germany, which was generated by wrapping a 360º roundshot around a virtual cylinder. Half of the participants saw an unmarked screen. The others saw a screen on which hardly noticeable small marks had been made on the upper left periphery. These marks resembled minor scratches. Circular vection was induced by rotating the visual stimulus around the seated participant, who indicated his feelings of vection using a force-feedback joystick mounted in front of him. At the end of a series of trials, participants completed an IPQ. Riecke et al. (2004a) reported that participants who saw the marked screen gave significantly higher presence scores (and also indicated a significantly higher experience of vection). IPQ total scores also showed a significant positive correlation with ratings of vection convincingness, and IPQ Involvement/Attention subscale scores had a significant negative correlation with vection onset time. The researchers stated that the increase in presence might have been mediated or caused by the increase in the ego-motion illusion.

Frame rate ▲ (see Meehan (2001 (3)))

Resolution ▲ (see Snow (1996 (1)))

Stereopsis ●

Stereoscopic vision is needed to judge relative distances, although visual scenes can be augmented or manipulated to simulate the effects of distance to some extent. HMDs support stereoscopic vision by providing slightly different views to the right and left eyes. In Caves and with projection screens and standard desktop monitors, a user usually achieves stereoscopic vision by wearing shutter glasses that allow the different scenes to be viewed by the right and left eyes at slightly different times. Experiments that have investigated how stereoscopic viewing may influence the sense of presence have used an HMD, a 6×8 ft rear projection screen, and a 50-in. (monitor) screen.

Two of the experiments in this group have been described previously. Cho et al. (2003) (see Section 3.4) found that participants who used shutter glasses to view a virtual fish tank displayed on a 50-in. screen gave significantly higher presence scores than those who viewed the scene without the shutter glasses.

Snow (1996 (2)) found that experimental participants who performed a series of part-tasks in a simple virtual world viewed through a stereoscopic HMD gave significantly higher presence ratings than participants who viewed the world monoscopically.

The use of stereoscopic viewing was one of the factors examined by Hendrix and Barfield (1996a (2)) in their series of experiments. The display was a 6 × 8 ft rear projection screen, and shutter glasses were used in the stereoscopic experimental condition. The virtual world was a 10 × 10 m room with checkerboard patterned floor and several familiar objects such as tables and chairs, a bookshelf, a soda machine, a photocopier machine, and paintings. The experimental task was to navigate around the room and become familiar with the environment in order to answer a questionnaire made available previously. Presence data were collected using 2 items on a 4-item questionnaire. Participants' presence scores were significantly higher after viewing the virtual world stereoscopically than after viewing the world without the shutter glasses.

ARI has had a long-term program investigating the requirements for using VEs to train dismounted soldiers. As part of this work, Singer et al. (1995) examined participants' performance in a series of part-tasks conducted in a series of simple virtual worlds. These tasks were chosen from a set collectively called the Virtual Environment Performance Battery (VEPAB) developed by Lampton et al. (1994) and included navigation, bins, fixed tracking, moving target, and distance estimation tasks. Participants viewed the worlds using a Flight Helmet HMD in either stereoscopic or monoscopic mode and with or without head tracking. These researchers found that stereoscopic viewing and head tracking had a significant interaction effect on presence such that participants in monoscopic, head-tracked condition gave higher scores than those in the monoscopic, untracked condition, while the reverse held for participants with stereoscopic viewing. (Performance measures for the tasks had no significant correlation with Witmer-Singer PQ scores.)

Tracking, face ○ (see Wang (2006 (1) (2)))

Tracking, head ○ (see Bailey and Witmer (1994 (2))), (see Bystrom and Barfield (1999)), (see Hendrix and Barfield (1996a (1))), (see Singer et al. (1995)), (see Snow (1996 (2)))

Update rate ●

Section 3.5 described two experiments that found that participants who viewed a VE at different update rates reported significantly more presence for faster updates rates. Snow (1996 (1)) also looked at the relationship between visual update rate and the sense of presence. Using an HMD with head tracking, participants in this experiment gave significantly higher presence ratings for the 16-Hz update rate than for the 12- or 8-Hz update rates. This finding is consistent with the other results.

4.9 World Characteristics

Replicated experiments have examined the relationship between the sense of presence and the number of audio sources, audio/visual presentation quality, and scene detail. There are no supporting data for the first of these. The results from an additional experiment did match the previous findings for audio/visual presentation quality. For scene detail, two additional experiments had a consistent finding that was different from the finding of the replicated experiment.

Audio cues ○ (see Brown et al. (2003)), (see Dinh et al. (1999)), (see Lawson (1998)), (see Welch (1999)), (see Whitelock et al. (2000))), ▲ (see Bormann (2005))

Audio source, nature of ▲ (see Larsson et al. (2004))

Manipulation, presence ▲ (see Casaneuva (2001 (2))), (see Michaud et al. (2004))

Manipulation, social presence ▲ (see Jeandrain (2004)), (see Thie and van Wijk (1998))

Olfactory cues ▲ (see Hoffman et al. (1999)), (see Dinh et al. (1999))

Presentation quality ●

As described in Section 3.6, Nuñez and Blake (2003a, 2003b) found that experimental participants gave significantly higher SUS Questionnaire scores and Witmer-Singer PQ scores for increased audio/visual presentation quality. As described in Section 4.3, Nicovich et al. (2005) used the Microsoft Flight Simulator 98 in manipulating the level of participants' interaction. They also used two levels of presentation quality. The high-presentation condition provided high-resolution graphics and sound. In the low-presentation condition, only low-resolution graphics were used, and participants did not receive any audio. Consistent with the finding of Nuñez and Blake, participants in the high-presentation condition reported significantly higher levels of presence than those reported by participants in the low-presentation condition.

Scene detail ●

Welch et al. (1996) found that high and low levels of scene detail were matched to high and low presence ratings. Two other experiments used VEs that were different from Welch et al. and found no differences.

The earliest of these experiments was another conducted by ARI researchers. This experiment used the Simulator Training Research Advanced Testbed for Aviation (STRATA) (see Johnson and Wightman (1995)). Two virtual worlds were used. One was a representation of the Hanchey Army Heliport (HAH) at Fort Rucker (Alabama). This is a "T-shaped" area with dimensions approximately 0.5 × 0.7 mi. This virtual world included all the features relevant to flight training missions, with structure colors matched from photos or videotape and signs and logos texture-mapped onto buildings. The second virtual world represented an approximately 10 × 10 mi portion of Arizona. This area was centered east of Phoenix and included part of the Mesa. It contained urban, residential, and desert terrain. Both worlds were viewed using helmet-mounted displays that were individually fitted to each participant and augmented with head tracking. Participants were seated in an AH-64A Apache helicopter pilot cockpit simulator with all flight instruments, controls, and motion displays switched off or covered. They navigated through the virtual worlds using joysticks attached to right and left arms of seat. Participants were represented in each virtual world by a black 2.5 × 3 ft virtual carpet they could see underneath their seat and feet when they looked down. The experimental task was a self-guided exploration of either the HAH or the Arizona virtual world. Using the Witmer-Singer PQ, Johnson and Wightman found no significant difference between the presence scores of the two groups of participants.

Researchers at the University of Cape Town (South Africa) explored the use of visual and audio mediation in virtual worlds used for cultural storytelling. Their goal was to see whether these forms of mediation could be used to facilitate interaction with users and increase their understanding of folklore (see Brown et al. (2003)). The research used a virtual world that presented a night scene of a cave situated in rough barren terrain. The interior of the cave was constructed using digital photographs of the caves in the Cederberg mountains of the Western Cape for rock textures. It contained a fire surrounded by three figures. As a participant approached the fire, one of these figures, the storyteller, stood in welcome. The participant was then asked to join the San hunters ("bushmen" in South Africa) around the fire and listen to a traditional San story. The researchers used conditions where San pictures were added to the cave walls, where sounds of the fire crackling and night insects were provided, where both these visual and audio mediations were included, and where no mediations were used. Participants viewed the virtual world on a desktop monitor. This time, the presence was measured using the IPQ, but, again, the additional visual details were not related to any significant difference among the presences scores. (The additional detail significantly increased participants' ratings of involvement.)

Speed of user movement ▲ (see Witmer and Kline (1998 (2)))

Tactile cues ○ (see Dinh et al. (1999)), (see Noel et al. (2004))

5. Conclusions

This document takes a high-level look at the results of many hours of hard work performed by a large number of researchers. It is not possible to discuss every experiment that has been mentioned to the extent that it deserves. In particular, many experiments had objectives that extended beyond the "sense of presence," and those aspects are not identified.

What can be learned from this body of work? First, it is important to remember that presence has usually been assessed in terms of self-report measures that are useful for comparing results across some experiment factor(s). The meaning of a score, rating, or other value in absolute terms is unknown. Secondly, the virtual worlds, experimental tasks, and participant populations that have been used are unlikely to be representative of practical applications. These choices were usually made for good reasons, such as to avoid confounding the results and to keep experimental costs within budget. So, while past research has provided some indications of which interface characteristics may be able increase or decrease a user's sense of presence, the findings must be applied cautiously. Findings supported by a replicated study and additional experiments across a wide variety of VEs would be the most likely to hold under different circumstances. Although 10 interface characteristics have been the focus of a replicated experiment, only 2 of these have been examined by as many as 2 additional experiments. However, if a series of replications is counted as a single experiment, then seven interface characteristics had a consistent finding across four or more different interfaces, virtual worlds, experimental tasks, and/or participant populations.

The spatialization of audio cues is the only audio interface characteristic that has been examined in more than a single experiment. This is one of the two interface characteristics that had a consistent finding across a replicated experiment and two additional experiments in which spatialized audio cues were associated with a higher sense of presence than nonspatialized audio cues. Although examined in only one experiment, spatialized sounds generated using individualized HRTFs (as opposed to a generic HRTF) were associated with higher presence scores.

Avatar and agent characteristics have been a popular research topic in recent years. Two experiments were consistent in finding that behavioral realism was associated with higher levels of presence. The data are stronger on how the role of an avatar or agent may affect presence. As many as six experiments found that participants who interacted with an avatar or agent reported higher levels of presence than participants who were alone in a virtual world, even though the interaction was not required for task performance. Another three experiments found that just including an agent—one that does not interact with a participant—was not related to any significant increase in reported presence.

The potential roles of several interaction characteristics have been examined in isolated experiments. Only the use of haptic force feedback, the level of interaction provided, and the use of passive haptics have been examined in more than a single experiment. Several researchers have investigated the use of force feedback (delivered to a fingertip) to indicate when the user (or a user-controlled device) comes in contact with a hard surface. The use of force feedback was consistently associated with a higher level of presence when (1) pairs of remote participants were tasked to assemble blocks into different patterns, (2) pairs of remote participants passed blocks between themselves, (3) individuals trained in the control of a mobile robot, and (4) individuals used a telepresence system for microassembly. Finding a consistent result over this diverse range of tasks might indicate that this finding is generalizable over a range of circumstances. However, it is likely that the relationship between force feedback and presence is highly dependent on the purpose and form of that feedback. In many cases, researchers have reported difficulties

using force feedback devices that could adversely affect a user's sense of presence. A significant association between presence and the level of interaction supported by a VE was found in six experiments. Four of the six used an experimental task that involved vehicular control, although the range of vehicles used (two cars, a plane, and a bicycle) might serve to increase the generalizability of the results to some extent. All but one of the experiments compared the sense of presence across a condition with interaction and a condition where the participant was a passive observer. In the exception, participants were limited to counting the number of oncoming cars. More data on how different extents of interaction might be related to presence are needed. Another six experiments investigated the potential relationship between passive haptics and presence, this time with inconsistent results. Although these experiments differed in the extent and types of real objects that were aligned with virtual objects, this is an interface characteristics that could be expected to have a strong enough relationship with the sense of presence to show across a range of VEs. Yet, three of the experiments found no relationship. Of the remaining three, one found that the use of passive haptics had an effect on behavioral measures of presence but not on questionnaire scores.

The results of four experiments were inconsistent in finding a relationship between self-navigation and preset navigation in a virtual world. There are no obvious commonalities among the experiments that found a relationship and those that did not. If the task does not require user control of navigation, it is possible that the unwieldy nature of current navigation devices and methods makes it advisable to relieve a user of this burden. Method of navigation has, in fact, been the focus of a replicated experiment and one additional experiment. These three experiments found that participants who moved through a virtual world based on the direction of their gaze and walking-in-place reported significantly more presence than participants who used some form of mouse. It is important to note, however, that none of these experiments required any special motions, such as climbing stairs.

The importance of how a user is represented in a virtual world is still uncertain. One replicated experiment found no difference between the presence scores given by experimental participants who had a full-body self-avatar and participants represented by only a virtual pointer or hand, while another experiment found a significant difference. The results of two experiments that manipulated the fidelity of virtual hand representation also had inconsistent results.

Various aspects of how a user moves in the real world while visually immersed in a virtual world have been examined. These have included, for example, a user reaching out a hand to interact with a virtual object versus achieving the same function using a mouse or a user being seated versus standing while using an HMD. The only type of user movement examined in more than a single experiment is the illusion of self-motion (vection). The results of the two relevant experiments were inconsistent in finding any relationship between reported vection and the sense of presence.

While interface systems and the requirements of a particular application may constrain many decisions related to visual displays, some decisions are primarily limited by the computational burden. In this area, the use of dynamic shadows and rendering quality were the subject of two and four experiments, respectively. Findings were inconsistent in both cases. The use of texture mapping and a high quality of textures, each examined in two experiments, were found to be associated with a significantly higher sense of presence. Scene realism was the subject of an experiment that was later replicated, and these two experiments had different results. Another three experiments, however, found that the manner in which realism was increased in a virtual world was unrelated to any changes in presence scores.

The potential impact of different types of visual display devices on the sense of presence has been the subject of more experiments than any other single interface characteristic. One experiment that was replicated and extended in two additional experiments consistently found that pairs of participants who collaborated using two Cave display systems reported more presence than pairs who used desktop monitors. This finding was consistent with that of an earlier study. The data regarding differences in presence that may be associated with the use of (1) Caves or HMDs, (2) HMDs, projection screens, or desktop monitors, and (3) among other types of display devices are less clear. Two experiments that compared the use

of rear projection screens and desktop monitors were consistent in finding no significant difference in the presence scores reported by participants.

There are several interface characteristics whose importance varies with different types of visual display device. The tradeoffs that might be needed to increase FOV, for example, are different for an HMD than for a panoramic display. The relationship between FOV and the sense of presence has been the subject of 10 experiments. Eight of these experiments consistently found that participants reported higher levels of presence for larger FOVs. The remaining two experiments compared smaller FOVs, and the absence of any significant difference in reported presence between these more restricted FOVs might indicate a lower bound beneath which changes in FOV have no relationship with the sense of presence. The results of a replicated experiment and one additional experiment were consistent in finding that participants reported more presence for a virtual scene presented in the background (because of a foreground occlusion or mask) than for a foreground image. The two groups of researchers who conducted these experiments were investigating vection and theorized that the increase in presence was mediated, or caused, by the increase in the illusion of ego-motion.

The price of early stereoscopic HMDs and the computational costs associated with generating two sets of images for HMDs, Caves, and projection screens caused several researchers to investigate whether the use of stereoscopic viewing was related to increases in presence. Four experiments (two using HMDs and two using projection screens with shutter glasses) found that participants did report higher levels of presence for such viewing. However, this is a good example of where advances in technology and the concomitant price reductions have reduced the need for tradeoffs that favor monoscopic viewing.

The role of head tracking in supporting a more natural interaction with a virtual world would seem likely to be related to the sense of presence for most types of tasks, and this relationship would be strong enough to show under most conditions. Yet, one of the three experiments that investigated this relationship using HMDs and one of two experiments that used large projection screens failed to find a difference in the level of presence reported for head-tracking and no-head-tracking conditions.

The final visual display characteristic that was examined is update rate. A replicated experiment and one additional experiment found that the speed with which the contents of the visual display were updated to reflect changes in a virtual world was related to the sense of presence. The fastest update rate considered by any of these three experiments was 25 Hz. With the increase in computation speeds that has occurred over the last several years, the data from these experiments are becoming irrelevant. It is unknown, however, whether the range of update rates common with today’s computers is fast enough to allow this interface characteristic to be ignored.

Among the interface concerns that are categorized as world characteristics, three of four replicated experiments had consistent results. The first of these experiments found that higher levels of presence were associated with larger numbers of concurrent sound sources. The second experiment manipulated the quality of audio/visual stimuli. The finding that higher levels of presence were associated with a high quality of stimulus was supported in a more recent experiment. Scene detail, in terms of the number of details included in a virtual world, is a related but distinct characteristic. This is the other case of an interface characteristic being studied in a replicated experiment and by two other experiments. In this case, however, the consistent finding of the initial experiment and its replication was different from that of other experiments.

An important point has been made by more than one researcher: when it comes to presence, just adding *more textures, more resolution, more…* does not necessarily lead to continual increases in presence. Instead, it is important to present a consistent level of realism, since mismatches in realism seem to cause a conflict that impedes users’ sense of presence. (It is interesting to note that some types of interface consistency may also be important across collaborating users. One experiment found that pairs of collaborating participants who used dissimilar types of visual displays reported less presence than those who used the same type of displays.) Another important point is that several of the examined interface

characteristics can vary over a large range of values, and computational and interface device costs generally increase substantially at the extremes of the range. Consequently, it is important to determine if there is a “plateau effect” beyond which increases in presence are not cost effective.

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Acronyms and Abbreviations

1D	one-dimensional
2D	two-dimensional
3D	three-dimensional
5DT	Fifth Dimension Technologies
6D	six-dimensional
AC	alternating current
ACM	Association for Computing Machinery
ACT	Acceptance And Commitment Therapy
ADL	Advanced Distributed Learning
Ag/AgCI	silver-silver chloride
ANOVA	analysis of variance
API	Application Programming Interface
AR	Augmented Reality
ARI	U.S. Army Research Institute for the Behavioral and Social Sciences
ARS	Adjectival Response Scale
AQ	Acrophobia Questionnaire
ATHQ	Attitude Towards Height Questionnaire
BAT	Behavior Avoidance Test
BIP	break in presence
BIS/BAS	Behavioral Inhibition Scale/Behavioral Activation Scale
CATT	Computer-Aided Theater Technique
CD	compact disc
CE	Computer Experience
CHI	Computer-Human Interaction
CIS	Creative Imagination Scale
COVEN	Collaborative Virtual Environments
CRP	Corneal Reflex Pupillometer
CRT	cathode ray tube
CSWC	Computer Supported Cooperative Work
CVE	Collaborative Virtual Environment
DES	Dissociative Experience Scale
DIVE	Distributed Interactive Virtual Environment
DOF	degree of freedom

DSM-IV	Diagnostic and Statistical Manual of Mental Disorders 4th Edition
E^{2}I	Engagement, Enjoyment, and Immersion
ECG	electrocardiogram
ECHOES	EduCational Hypermedia On-LinE System
EDA	electrodermal activity
EKG	electrocardiogram
EMG	electromyography
EPQ	Eysenck Personality Questionnaire
EVEQ	Experimental Virtual Environment-Experience Questionnaire
FFi	Fear of Flying Inventory
fMRI	functional Magnetic Resonance Imaging
FOV	field of view
FPS	First Person Shooter
GFOV	geometric field of view
GSR	galvanic skin response
GX	Gesture Xtreme
HAH	Hanchey Army Heliport
H-Anim	humanoid animation
HAZMAT	hazardous materials
HCI	Human-Computer Interaction
HD	high definition
HFOV	horizontal field of view
HITLab	Human Interface Technology Laboratory
HMD	head-mounted display
HRP	Halden Reactor Project
HRTF	head-related transfer function
HRV	heart-rate variability
IBI	interbeat interval
IBM	International Business Machines
ICAT	International Conference on Artificial Telexistence
ICS	Individual Combatant Simulation
IDA	Institute for Defense Analyses
IEEE	Institute of Electrical and Electronics Engineers
IIS	Fraunhofer Institut für Integrierte Schaltungen (Fraunhofer Institute for Integrated Circuits)
IMI	Intrinsic Motivation Inventory
ImpSS	Impulsive Sensation Seeking
IPD	Interpupillary Distance

IPQ	Igroup Presence Questionnaire
IPO-SPQ	IPO Social Presence Questionnaire
IPT	immersive projection technology
IR	infrared
IRI	Interpersonal Reactivity Index
ISDN	Integrated Services Digital Network
ITC-SOPI	Independent Television Commission-Sense of Presence Inventory
KTH	Kungliga Tekniska Högskolan (Royal Institute of Technology, Sweden)
LAN	local area network
LCD	Liquid Crystal Display
M.I.N.D.	Media Interface and Network Design
MBTI	Myers-Briggs Type Indicator
MCQ	Memory Characteristic Questionnaire
MEC-SPQ	Measures, Effects, Conditions-Spatial Presence Questionnaire
MIP	Mood Induction Procedure
MIPS	Microprocessor without Interlocked Pipeline Stages
MOUT	Military Operations in Urban Terrain
MSSS	Motion Sickness Susceptibility Survey
MSQ	Motion Sickness Questionnaire
NAVE	Non-expensive Automatic Virtual Environment
NASA	National Aeronautics and Space Administration
NEO	Neuroticism, Extraversion, Openness
NEO-FFI	NEO Five-Factor Inventory
NFS UG	Need for Speed Underground
NLP	Neurolinguistic Programming
NordCHI	Nordic Conference on Computer Human Interface
NT	New Technology
NTSC	National Television System(s) Committee
OCED	Organisation for Economic Co-operation and Development
OUSD/P&R	Office of the Under Secretary of Defense for Personnel and Readiness
PA	Projection Augmented
PANAS	Positive and Negative Affect Schedule
PC	personal computer
PDA	Personal Digital Assistant
PIAVCA	Platform Independent Architecture for Virtual Characters and Avatars
PLUM	Programme on Learner Use of Media
POEMS	Perceptually Oriented Ego-Motion Simulation
POSTECH	Pohang University of Science and Technology

PQ	(Witmer-Singer) Presence Questionnaire
PRCS	Personal Report of Confidence as a Public Speaker
QAF	Questionnaire on Attitudes Toward Flying
OPQ	Object Presence Questionnaire
RAT	Robust Audio Tool
RE	Real Environment
RISC	reduced instruction set computer
RJPQ	Reality Judgment and Presence Questionnaire
RR	Research Report
RWP	redirected walking-in-place
SAD	Social Avoidance and Distress
SAGAT	Situation Awareness Global Assessment Technique
SAM	Self-Assessment Manikin
SCL-90	Symptom Checklist-90
SFQ	Scenario Feedback Questionnaire
SGI	Silicon Graphics, Inc.
SICS	Swedish Institute of Computer Science
SID	International Society for Informational Displays
SIGCHI	Special Interest Group on Computer-Human Interaction
SIGGRAPH	Special Interest Group on Computer Graphics
SPQ	Scenario Presence Questionnaire
SSC	Short Symptom Checklist
STRATA	Simulator Training Research Advanced Testbed for Aviation
STRT	secondary task reaction time
SUDS	Subjective Unit of Discomfort Scale
SUS	Slater-Usoh-Steed
SVE	Shared Virtual Environment Simple Virtual Environment
SVGA	Super Video Graphics Array
SVUP	Swedish User-Viewer Presence Questionnaire
TAI	Test Anxiety Inventory
TAS	Tellegen Absorption Scale
TCP/IP	Transmission Control Protocol/Internet Protocol
TLX	Task Load Index
TR	Technical Report
TSI	transformed social interaction
TV	television
UCL	University College London

UK	United Kingdom
UKVRSIG	UK Virtual Reality Special Interest Group
UNC	University of North Carolina
USB	Universal Serial Bus
UV	ultraviolet
VAS	Visual Analogue Scale
VE	Virtual Environment
VE^2	Virtual Engineering Environment
VEPAB	Virtual Environment Performance Assessment Battery
VGA	Virtual Guiding Avatar
VPX	Virtual Path Cross-Connect
VR	Virtual Reality
VR/AR	Virtual Reality/Augmented Reality
VRAIS	Virtual Reality Annual International Symposium
VRET	Virtual Reality Exposure Therapy
VRML	Virtual Reality Modeling Language
VRST	Virtual Reality Software and Technology
VVC	Virtual Video Conference
VVQ	Verbalizer-Visualizer Questionnaire
WAN	wide area network
ZKPQ-ImpSS	Zuckerman-Kuhlmann Personality Questionnaire-Impulsive Sensation Seeking

Appendix A. Summaries of Experimental Studies

Appendix A. Summaries of Experimental Studies

Note for the Appendix. In the discussion of the experiments, the italicized items (except for paper Titles) do not relate directly to Presence (e.g., Findings (7)–(11) for the first experiment listed [Allen 2001]).

[Allen 2001] Allen, R. C., and Singer, M. J. (2001). Presence in altered environments: Changing parameters and changing presence. *Proceedings of the 9th International Conference on Human-Computer Interaction,* New Orleans, USA, August, 639–643. See also Allen, R. C. (2000). *The effect of restricted field of view on locomotion tasks, head movements, and motion sickness*. Doctoral dissertation, University of Central Florida, Orlando.

Factors:		Field of view (FOV) (virtual 48º × 36º, real Restricted 48º × 36º, real Horizontal Visual Field 96º × 36º, real Lower Visual Field 48º × 72º, real Normal), self-representation (body, right hand and fanny pack when 2 ft from a trashcan).
Computing platform:		Silicon Graphics, Inc. (SGI) Onyx RealityEngine2 with eight 200-MHz R4400 processors, 256 MB random access memory (RAM). Software Systems Multigen II v1.5 and in-house software.
Visual display:		For Virtual Environment (VE): Virtual Research V8 head-mounted display (HMD) with FOV 48º × 36º, 1820 × 480 color pixels per eye. Participant eye height and Interpupillary Distance (IPD) used to adjust display. For real world: HMD mockup with plastic goggles including cardboard cutouts for masks.
Auditory display:		Sound of collisions and white noise presented over HMD headphones.
Tracking:		For VE: Head, shoulder, feet, right arm, and right hand motions using 6 Ascension Technology's Flock-of-Birds sensors and tracked by an Ascension Technology's MotionStar (wired version) with an extended range transmitter. For real world: Precision Navigation Inc. TCM2/50 Electronic Compass Module mounted on HMD mockup.
Navigation:		Walking-in-place.
Object manipulation:		In VE, used joystick to move virtual hand close to fanny pack and pick up, then drop, a virtual ball. In real world used real balls carried in a fanny pack.
Virtual world:		Series of 3 rooms filled with typical office furniture. Self-representation as virtual body or virtual right hand (and fanny pack).
Training:		Movement training in 2 separate practice environments, included general movement (VE condition only), collision avoidance, path following. Then, in 1 practice environment, search training involving locating 2 trashcan targets in sequential order and dropping a ball inside each.
Experimental task:		For guided movement task, in first room, follow a path defined by arrows as quickly and accurately as possible, minimizing collisions. For search task, in each remaining room, search for 2 trashcan targets in sequential order and drop a ball inside each.
Participants:		90 participants recruited from a university campus; 36 males; age range 18 to 45; mean age 21 years.
Study design:		Between-subjects.
Presence measures:		32-item Witmer-Singer Presence Questionnaire (PQ) Version 3.0.
Person-related meas.:		Witmer-Singer Immersive Tendencies Questionnaire (ITQ).
Task-related measures:		Kennedy Simulator Sickness Questionnaire (SSQ).
Performance measures:		*Guided movement time*, *number of collisions*, *search time*.
Other measures:		Head movement (yaw, pitch).
Findings:	(1)	Participants with no self-avatar body gave significantly higher scores for PQ Natural subscale.

(2) Virtual (48º × 36º) participants gave significantly higher scores for PQ Total and all subscales except Natural than real Restricted (48º × 36º) participants.
(3) FOV in real world had a significant relationship with PQ Total and all PQ subscales except Involved/Control subscale, where Normal group rated Interface Quality higher than Restricted and Lower Visual Field groups, and Normal group rated total PQ, Naturalness, and Resolution higher than Restricted group.
(4) For real-world participants, FOV had a significant positive correlation with PQ Total and Natural, Interface Quality, and Resolution subscales.
(5) For VE participants, ITQ Focus subscale scores had a significant positive correlation with PQ Total, Involved/Control and Interface Quality subscale scores, and ITQ Games subscale scores had a significant positive correlation with PQ Total and Involved Control subscale scores. For real-world participants, ITQ Games subscale scores had a significant positive correlation with PQ Resolution subscale scores.
(6) For VE participants, SSQ Total score had a significant negative correlation with PQ Total and Involved Control subscale scores; SSQ Oculomotor Discomfort with PQ Total, Involved/Control, and Natural subscales; and SSQ Disorientation with PQ Natural subscale. For real-world participants, SSQ Total and subscale scores had no significant correlations with PQ Total and subscale scores.
(7) For the guided movement task, self-representation had a significant relationship with time taken, with the Body group taking significantly longer. Time taken by the disembodied group also was significant different to time taken by the Restricted group. Self-representation had no significant relationship with collision score or head movement; in each case the score for the (pooled) VE groups differed significantly from that of the Restricted group.
(8) For the search task, self-representation had no significant relationship with time taken, collision score or head movement; in each case, the score for the (pooled) VE groups differed significantly from that of the Restricted group.
(9) Self-representation had no significant relationship with pitch or yaw or on change (pre, post exposure) in SSQ Total or subscale scores.
(10) Type of environment/FOV was significantly related to post-exposure SSQ scores between the (pooled) VE and (pooled) real-world groups only, with VE participants reporting significantly higher SSQ Total score, and higher Nausea, Oculomotor Discomfort, and Disorientation subscale scores.
(11) For Interpupillary Distance *participants, SSQ scores had a significant positive correlation with Motion Sickness Questionnaire (MSQ) Total, subscale A, and subscale B with SSQ Disorientation.*

[Axelsson 2001] Axelsson, A.-S., Abelin, Å., Heldal, I., Schroeder, R., and Wideström, J. (2001). Cubes in the cube: A comparison of a puzzle-solving task in a virtual and a real environment. *CyberPsychology & Behavior, 4* (2), 279–286.

Factors:	Visual display (1 participant in 5-sided Cave and 1 using desktop system).
Computing platform:	SGI Onyx 2 InfiniteReality with 14 MIPS[1] R10000 processors, 2 GB RAM, 3 graphics pipes. SGI O2 with 1 MIPS R10000 processor, 256 MB RAM. dVise 6.0 software with SGI Performer renderer.
Visual display:	3 × 3 × 3 m TAN 3D Cube with projection on 5 walls (no ceiling), stereoscopic viewing using StereoGraphics Corporation CrystalEyes shutter glasses. 19-in. monitor with FOV ~ 60°. Frame rate ≥ 30 Hz.
Auditory display:	Communication via telephone headset.
Tracking:	Polhemus tracker attached to shutter glasses.

[1] MIPS, for Microprocessor without Interlocked Pipeline Stages, is a reduced instruction set computer (RISC) microprocessor architecture developed by MIPS Technologies, Inc.

Navigation:	In the Cube system: by moving around physically and gesturing with dVise three-dimensional (3D) mouse. In the desktop system: by moving middle button on standard 3-button two-dimensional (2D) mouse.
Object manipulation:	In the Cube system: blocks selected and moved by a participant putting his hand into a virtual cube and pressing 3D mouse button. In the desktop system: blocks selected by clicking on the cube with the left button, then moved by keep right button pressed and moving the mouse; cubes rotated using a combination of the right mouse button and shift key.
Virtual world:	Empty room containing 8 blocks with 1 of 6 different colors on each side. Blocks were 30 cm each edge. Self-representation as identical dVise avatars.
Experimental task:	Two participants cooperate to solve a puzzle by arranging blocks into a cube, such that each side of the completed cube displays a single color. 20-min time limit.
Participants:	22 pairs of participants; 26 males; mean age 34 years.
Study design:	Between-subjects.
Presence measures:	2-item presence questionnaire, 1-item place-to-visit rating, 2-item co-presence questionnaire.
Task-related measures:	*2-item questionnaire on own and partner's contribution to task, 1-item questionnaire on amount of verbal communication, 1-item on extent of collaboration*.
Findings:	(1) Cave participants reported significantly higher presence scores, but visual display had no significant relationship with co-presence.
	(2) Co-presence had a significant positive correlation with presence in the desktop environment but not in the Cave environment.
	(3) Cave participants reported significantly more contribution.
	(4) Visual display had no significant relationship with amount of communication.
	(5) Visual display had no significant relationship with collaboration between Cave and desktop system, but was associated with a significant difference for Real Environment (RE) and VEs with more collaboration reported for RE.

[Axelsson 1999] Axelsson, A.-S., Abelin, Å., Heldal, I., Nilsson, A., Schroeder, R., and Wideström, J. (1999). Collaboration and communication in multi-user virtual environments: A comparison of desktop and immersive virtual reality systems for molecular visualization. *Proceedings of the 6th UKVRSIG Conference*, University of Salford, UK, September, 107–117.

Factors:	Visual display (5-sided Cave, desktop).
Computing platform:	Cave system used SGI Onyx2 InfiniteReality with 8 MIPS R10000 processors, 2 GB RAM, 3 graphics pipes. SGI O2 with 1 MIPS R10000 processor, 256 MB RAM. dVise 6.0 software with SGI Performer renderer, Lake Huron 3.0 for audio. Desktop system used SGI O2s with an MIPS R10000 processor and 256 MB RAM.
Visual display:	3 × 3 × 3 m TAN 3D Cube with projections on 5 walls (no ceiling), stereoscopic viewing using StereoGraphics Corporation CrystalEyes shutter glasses; frame rate 4–6 Hz. 19-in. monitor.
Auditory display:	8 loudspeakers and a Vibrafloor used in the Cave system.
Tracking:	Polhemus tracker attached to shutter glasses.
Navigation:	In the Cube system: using dVise 3D mouse. In the desktop system: by moving middle button on standard 2D mouse.
Object manipulation:	Use of a mouse button to mark objects in the desktop system.
Virtual world:	An open space that contained ball-and-stick molecular models of similar size (1,200 atoms); Myoglobin in Cube system and Cytochrome-2 in desktop system. Unique sounds associated with the amino acids and iron atom in the Cave system. Desktop system allowed highlighting a molecule.
Training:	Demonstration and practice in how to navigate and manipulate objects in the VE, and how to communicate with partner. 5–10 min.

Experimental task: First locate the single iron atom within the molecule and identify the atoms connected to it. Then, count the number of carbon rings in the molecule. 15 min allowed for each task. Questionnaire completed after each task.

Participants: 100 undergraduates, working in groups of 4 to 6 in the Cave-type display and in pairs with the desktop system. Data for co-presence, collaboration, and communication were collected for only the navigator and his collaborator in the Cube system (40 participants), other participants were bystanders.

Study design: Within-subject.

Presence measures: 2-item presence questionnaire, 1-item co-presence questionnaire.

Task-related measures: 1-item experienced collaboration, 1-item naturalness of communication, *1-item leadership, 1-item pleasantness, 1 item enjoyment*.

Findings:

(1) Cave participants reported significantly higher presence, but visual display had no significant relationship with co-presence.

(2) In the Cave condition, presence had a significant positive correlation with co-presence and collaboration but not with communication. In the desktop condition, no significant correlations between presence and any of co-presence, collaboration, or communication.

(3) In the both systems, co-presence had a significant positive correlation with collaboration but not with communication.

(4) Visual display had no significant relationship with communication, collaboration, or leadership.

(5) Visual display had a significant relationship with rating of pleasantness and enjoyment, with increases in each found for the Cube display.

(6) Collaboration had a significant positive correlation with communication for both types of display.

[Bailenson 2006] Bailenson, J. N., and Yee, N. (2006). A longitudinal study of task performance, head movements, subjective report, simulator sickness, and transformed social interaction in collaborative virtual environments. *Presence, 15* (6), 699–716. See also Yee, N., and Bailenson, J. (2006). Walk a mile in digital shoes: The Impact of embodied perspective-taking on the reduction of negative stereotyping in immersive virtual environments. *Proceedings of the 9th International Workshop on Presence*, Cleveland, USA, August, 147–156.

Factors: Transformed social interaction (normal, face similarity, mimic), trial day.

Computing platform: 700-MHz Pentium IV computer with NVIDIA GeForce FX 5200 or 5950 graphics card, system latency (maximum) 45 ms.

Visual display: Virtual Research V8 stereoscopic HMD with dual 680 × 480 resolution or nVisor SX HMD with dual 1280 × 1024 resolution. On both, FOV 50º × 38º, frame rate 60 Hz.

Auditory display: Speakers placed near station (and participants wore microphones).

Tracking: InterSense IS-250 for head tracking.

Navigation: None.

Object manipulation: None.

Virtual world: Collaborative Virtual Environment (CVE) with participants seated around a table and only one other participant visible at a time. In normal condition, participants saw one another wearing their own faces and gesturing veridical. In face-similarity condition, each participant saw the other 2 participants wearing his own face and gesturing veridically. In mimic condition, each participant saw the others wearing their own faces but mimicking his own head movements at a 4-sec lag. Avatars exhibited head movements, speech, mouth movements, and blinking.

Experimental task: Collaborate on a series of problem solving tasks over 15 trials spread across a 10-week period. Problems verbally administered by an experimenter. 3 types of problems (20 questions × 3, reverse remote association × 3, insight problem) for each session, with 3-min breaks between each type of problem. 35 to 40 min/trial.

Participants: 3 groups of 3 undergraduates (1 group of males, 2 groups of females) from introductory communication course. None had previously used immersive Virtual Reality (VR) more than once.
Study design: Within-trial.
Presence measures: 4-item questionnaire, 5-item co-presence questionnaire.
Task-related measures: *10-item entitativity questionnaire*, *16-item Kennedy SSQ, measure of visual inattention*.
Performance measures: Compound measure for each problem type, based on quantity, quality, and speed.
Findings:
(1) Transformed social interaction had no significant relationship with presence, co-presence, or entitativity scores.
(2) Co-presence and entitativity scores were significantly higher than presence scores.
(3) Presence and co-presence had no significant correlation with trial day.
(4) Entitativity had a significant positive correlation with trial day.
(5) Transformed social interaction had no main effect on performance but had an interaction with problem type, such that performance in 20-questions problem in face similarity condition was significantly better than performance for that problem type in both the mimic and normal conditions.
(6) Transformed social interaction had no significant relationship with SSQ scores.
(7) SSQ scores decreased significantly over successive trials.
(8) Transformed social interaction had no significant relationship with visual inattention.
(9) Visual inattention increased significantly over successive trials.

[Bailenson 2006] Bailenson, J. N., Yee, N., Merget, D., and Schroeder, R. (2006). The effect of behavioral realism and form realism of real-time avatar faces on verbal disclosure, nonverbal disclosure, emotion recognition, and co-presence in dyadic interaction. *Presence, 15* (4), 359–372.

Factors: Avatar realism (face-tracked real faces, emotibox, voice only).
Computing platform: Microsoft NetMeeting videoconference application. Desktop monitor equipped with Logitech Quick-Cam Messenger digital camera. Nevenvision Facial Face Tracker integrated into Vizard 2.5 to support emotibox generation. Participants wore headset microphones.
Visual display: Desktop monitor.
Tracking: None.
Navigation: None.
Object manipulation: None.
Virtual world: Presentation of emotibox in 1 experimental condition. This based on tracking 8 facial anchor points.
Experimental task: First task: verbal self-disclosure, using 6 pairs of questions. In turn, a participant read the next question on his desktop monitor and asked it of the other participants. Second task: for each of 7 emotions, a participant had to convey the emotion facially for 10 sec for the other participant to guess (voice-only participants used sounds.) One participant did the full 7, and then the other participant did 7.
Participants: 15 pairs of undergraduates; 12 males.
Study design: Between-groups.
Presence measures: 4-item co-presence questionnaire.
Task-related measures: *Composite measure of verbal self-disclosure based on blind coder ratings of friendliness, honesty, and how revealing answers to questions were. Measure of nonverbal self-disclosure based on tracked facial expressions.*
Performance measures: *Emotion detection score*.
Findings:
(1) Participants gave significantly higher co-presence scores for voice-only compared with use of emotibox. Gender has no significant relationship with co-presence scores.

(2) *Emotional detection scores were significantly lower for the emotibox condition than either voice-only or videoconference conditions. Gender was not related to scores.*

(3) *For verbal self-disclosure, disclosure was significantly higher in the voice-only and emotibox conditions compared to video conferencing. Gender was not related to verbal self-disclosure.*

(4) *For nonverbal disclosure, there was significantly more disclosure in the voice-only condition compared to the emotibox or videoconference conditions. Gender was not related to nonverbal self-disclosure.*

[Bailenson 2004a] Bailenson, J. N., Swinth, K., Hoyt, C., Persky, S., Dimov, A., and Blascovic, J. (2004a). The independent and interactive effects of embodied agent appearance and behavior on self-report, cognitive, and behavioral markers of copresence in immersive virtual environments. *Presence, 14* (4), 379–393.

Factors: Representation type (human, teddy bear, blockhead), behavioral realism (static head movement, random movement, mimic movement, recorded movement).

Computing Platform: 450-MHz Pentium III dual processor with Evans 7 Sutherland Tornado 3000 dual pipe graphics card, latency < 65 ms. Software Vizard 2.0 with Human representation developed using 3dMeNow.

Visual display: Virtual Research V8 stereoscopic HMD, 680 × 480 resolution, 50° × 38° visual field, average frame rate 36 Hz.

Tracking: Head tracking using InterSense IS-300. System; latency 65 ms.

Navigation: Logitech RumblePad Pro input device.

Object manipulation: Logitech RumblePad Pro input device.

Virtual world: Participant seated at a table facing an embodied agent with head and shoulders visible. Agent portrayed phototrealistically with preset blinking pattern but no facial gestures. 8 letters and numbers were shown on a label placed on agent's chest. No self-representation.

Training: Instruction on how to wear HMD and how to use the game pad.

Experimental task: Once seated across from agent, use game pad to scroll through instructional text that appeared above agent's head. Observe agent for 90 sec. Then answer questionnaires. Next approach agent and examine further.

Participants: 146 undergraduates; 73 males; age range 18 to 27; mean age 19.6 years.

Study design: Between-subjects.

Presence measures: 3-item co-presence questionnaire, minimum interpersonal distance and reversal count in approaching agent.

Task-related measures: Recall of characters on agent's label, willingness to perform embarrassing actions rating (used as co-marker for co-presence), *affect rating for avatar*.

Findings:

(1) Participants in random head movement behavior condition gave significantly higher co-presence scores than those in static head movement. Within the blockhead condition, random head movement had significantly higher co-presence scores than static or mimic head movement. Within the teddy bear condition, mimic head movements had significantly higher co-presence scores than static or recorded head movements, and co-presence was significantly higher in the random head movement than for static or recorded head movements.

(2) Co-presence questionnaire scores had a significant negative correlation with willingness to perform embarrassing acts, a significant positive correlation with likeability, and no significant relationship with memory scores.

(3) Co-presence questionnaire scores had no significant correlation with either interpersonal distance or reversal count.

(4) Participants with human representation were significantly less likely to perform embarrassing acts in front of the embodied agent than participants with teddy bear representation.

(5) Behavioral realism had no significant relationship with interpersonal distance.

(6) Representation type had no significant relationship with interpersonal distance.
(7) Behavioral realism had a significant relationship with reversal count, with participants in the random head movement condition performing significantly fewer reversals that participants in any of the other head movement conditions.
(8) Participants with human and teddy bear representations reported significantly more likeability than those in the blockhead condition.
(9) Behavioral realism had a significant relationship with memory, with worse memory for the mimic condition than for either the static or random movement conditions. In the blockhead condition, memory was better in the random movement condition than in either the mimic or recorded conditions. Within the human condition, memory was worse for mimic and random movement conditions than for static or recorded conditions.

[Bailenson 2004b (1)] Bailenson, J. N., Aharoni, E., Beall, A. C., Guadagno, R. E., Dimov, A., and Blascovich, J. (2004b). Comparing behavioral and self-report measures of embodied agents' social presence in immersive virtual environments. *Proceedings of the 7th Annual International Workshop on Presence*, Valencia, Spain, October, 216–223.

Factors: Identity (tutor, stranger).
Computing Platform: Dual pipe OpenGL personal computer (PC) graphics updated at 60 Hz. Average latency 55 ms.
Visual display: HMD.
Tracking: 6 DOF head tracking using InterSense IS-300, video position tracking using WorldViz PPT.
Navigation: Real movement.
Object manipulation: None.
Virtual world: Open space containing a stationary agent with a label containing one word in his chest. Explorable space 2.6 × 2.5 × 2.5 m. Participants' eye height matched to eye height of agent.
Training: Interacted with a text-based tutoring algorithm, in second part presented with a series of 20 facts about American culture and later tested on these facts. Then entered virtual world and instructed on navigation with ~ 1 min practice in walking.
Experimental task: Approach virtual agent from left side, right side, and then to the front and center. Read aloud label on front of agent. 2 trials. Participants were told that either the agent was an embodiment of the computer tutor they had previously worked with, or a represented an unknown computer algorithm.
Participants: 72 psychology students; 36 males; age range 15 to 30; median age 20 years.
Study design: Between-subjects.
Presence measures: 5-item co-presence questionnaire, minimum interpersonal distance.
Person-related meas.: Gender.
Task-related measures: 2-item likeability questionnaire, 3-item status questionnaire, 2-item interest questionnaire (used as markers of co-presence).
Findings:
(1) Identity had no significant relationship with co-presence.
(2) Co-presence had no significant correlation with interpersonal distance.
(3) Gender had no significant relationship with interpersonal distance or co-presence.
(4) On the first trial only, participants left significantly more personal space around the tutor.
(5) Identity had no significant of any of likeability, status, or interest.

[Bailenson 2004b (2)] Bailenson, J. N., Aharoni, E., Beall, A. C., Guadagno, R. E., Dimov, A., and Blascovich, J. (2004b). Comparing behavioral and self-report measures of embodied agents' social presence in immersive virtual environments. *Proceedings of the 7th Annual International Workshop on Presence*, Valencia, Spain, October, 216–223.

Factors:		Identity (tutor, stranger).
Computing Platform…		
Experimental task:		As in [Bailenson 2004b (1)], except participants performed 6 trials.
Participants:		48 psychology students; 27 males; age range 18 to 23; median age 19 years.
Study design:		Between-subjects.
Presence measures:		5-item co-presence questionnaire, minimum interpersonal distance.
Person-related meas.:		Gender.
Task-related measures:		2-item likeability questionnaire (used as a marker of co-presence).
Findings:	(1)	Identity had no significant relationship with co-presence.
	(2)	Co-presence had no significant correlation with interpersonal distance.
	(3)	Gender had no significant relationship with interpersonal distance or co-presence.
	(4)	Participants who approached the tutor left a significantly larger interpersonal distance.
	(5)	Identity had no significant relationship with likeability.

[Bailenson 2004c] Bailenson, J. N., Beall, A. C., Blascovich, J., Loomis, J., and Turk, M. (2004c). *Non-zero sum gaze and persuasion.* Paper presented at 54th Annual Conference of the International Communication Association, New Orleans, USA, May. See also Bailenson, J. N., Beall, A. C., Loomis, J., Blascovich, J., and Turk, M. (2005). Transformed social interaction, augmented gaze, and social influence in immersive virtual environments. *Human Communication Research, 31* (4), 511–537.

Factors:	Participant gender (male, female), presenter gaze (natural, augmented, reduced).
Computing Platform:	450-MHz Intel Pentium III with dual processors, Evans and Sutherland Tornado 3000 graphics cards.
Visual display:	Virtual Research V8 stereoscopic HMD with 680 × 480 resolution, FOV 50° H × 38° V at full 100% overlap. Scene rendered at ~ 60 Hz, with latency < 65 ms.
Audio display:	Worn full-duplex intercom device.
Tracking:	Head tracking.
Navigation:	None.
Object manipulation:	Game pad used to record responses.
Virtual world:	Room containing a round table around which 3 avatars were seated. In the natural condition, the presenter's avatar reproduced his gaze at each of the 2 participants. In the augmented condition, the presenter's gaze was directed at both other participants 100% of the time. In the reduced condition, the presenter's gaze looked down at his monitor 100% of the time. Listeners' head movements were reproduced exactly. All avatars blinked and moved their lips when that participant spoke. Participants could see own torsos, as appropriate.
Training:	In virtual world, presenter facilitated introductions and discussed how the immersive CVE and game pad worked.
Experimental task:	Participate in a discussion with a presenter (experimenter) and one other listener. Presented read a persuasive passage in 4 sections, leading a discussion after each section for ~ 90 sec. After passage read, presenter verbally administered 3 Likert-scale agreement questions and 3 recall multiple-choice questions about the passage. Participants responded using game pad.
Participants:	72 introductory psychology students; age range 18 to 25; mean age 19.6 years.
Study design:	Between-subjects.
Presence measures:	7-item social presence questionnaire.

Task-related measures: *Average agreement score*; *estimation of percent of time presenter was looking at this participant*, *other participant*, *no one*; *written paragraphs about presenter, other participant, and virtual conference*. Memory score (used as a cognitive marker of social presence).

Findings:
(1) Participant gender had no significant relationship with social presence.
(2) Participants in the augmented gaze condition reported significantly less presence than those in the other conditions. Participant gender and presenter gaze had a significant interaction, with female participants reporting more presence in the natural condition than males.
(3) Males scored significantly higher on recall test. Presenter gaze had no significant relationship with recall.
(4) Gaze direction (toward participant answering question versus toward other participant) had a significant relationship with gaze estimation percentage, with participants indicating that they receiving more of presenter's gaze than the "other" participant did. Participant gender and presenter gaze had no significant relationship with gaze estimation percentage. Presenter gaze and gaze direction had a significant interaction, with participants in the augmented condition perceiving more gaze directed at themselves compared to the other two presenter gaze conditions.
(5) Participant gender and presenter gaze had no significant relationship with total gaze (summation of 3 estimation percentages).
(6) Females agreed significantly less overall than males. For with augmented gaze, agreement was significantly higher than in other conditions. Gender and gaze had a significant interaction, with females in the augmented condition demonstrating higher agreement than other gaze conditions, while males did not show a difference between conditions.

[Bailenson 2003 (1)] Bailenson, J. N., Blascovich, J., Beall, A. C., and Loomis, J. M. (2003). Interpersonal distance in immersive virtual environments. *Personality and Social Psychology Bulletin, 29,* 1–15.

Factors: Virtual human gender (male, female), gaze behavior (mutual gaze, eyes closed), participant gender (male, female), agency (human-controlled avatar, computer-controlled agent).

Computing platform: 450-MHz Pentium III with dual processors, with Evans and Sutherland Tornado 3000 dual-pipe graphics card. System latency maximum of 65 ms.

Visual display: Virtual Research V8 stereoscopic HMD with resolution 680 × 480, FOV 50ºH × 38ºV. Frame rate 36 Hz. Participant eye height used to adjust display.

Tracking: Head tracking using InterSense IS-300 and in-house passive optical position sensing system.

Navigation: Actual walking.

Object manipulation: None.

Virtual world: 7.2 × 6.4 × 4.5 m textured floor. Mutual gaze was indicated by appropriate head movements of the avatar and occasional blinking, otherwise the avatar's head was stationary and the eyes closed. Shirt of virtual human had a label on the front depicting a name and a label on the back giving numbers. Participant eye height set at ~ 1.7 m. Participant not represented. No collision detection.

Training: Exploration of an empty room for approximately 1 min.

Experimental task: Move through a series of rooms to find a stationary person with shirt bearing labels on front and back. Walk to the person and read the back label and then the front label. 5 trials in each block varying in virtual human details. 2 blocks of trials, 1 with female virtual human, 1 with male. After trials and completing recall test, participants redonned HMD to complete social presence questionnaire while in virtual world.

Participants: 80 introductory psychology students; age range 18 to 30; mean age 19.6 years.

Study design: Within-subjects for virtual human gender, between-subjects for gaze behavior, participant gender, and agency.
Presence measures: 5-item social presence questionnaire, minimum interpersonal distance.
Task-related measures: *Affect rating for liking of virtual humans*.
Performance measures: *Recall test on names and numbers on patches, matching test on names and number.*
Findings:
(1) Mutual gaze behavior was associated with significantly higher social presence scores.
(2) Virtual human gender, participant gender, and agency had no significant relationship with social presence.
(3) A male virtual human was associated with significantly increased minimum distance. Gaze behavior, participant gender, and agency had no significant relationship with minimum distance. Gaze behavior and agency had a significant interaction, with minimum distance greater from agents with head movement and blinking than agents without. Participant gender and agency had a significant interaction, with minimum distance greater for female participants.
(4) Social presence had no significant correlation with minimum interpersonal distance.
(5) Virtual human gender only had a significant relationship with liking of virtual human, with participants liking the male virtual human more.
(6) Agency only had a significant relationship with memory, with higher recall for names and numbers on avatars than those on agents.

[Bailenson 2003 (2)] Bailenson, J. N., Blascovich, J., Beall, A. C., and Loomis, J. M. (2003). Interpersonal distance in immersive virtual environments. *Personality and Social Psychology Bulletin, 29,* 1–15.

Factors: Virtual human gender (male, female), gaze behavior (mutual gaze, eyes closed), participant gender (male, female), agency (human-controlled avatar, computer-controlled agent), contact time (before contact, after contact).
Computing platform…
Object manipulation: As in Bailenson 2003 (1).
Virtual world: 7.2 × 6.4 × 4.5 m space with no walls or ceiling, but floating bar used to indicate presence of physical room walls. Participant eye height set at ~ 1.7 m. No self-representation. No collision detection.
Navigation: Actual walking.
Training: Exploration of empty room for approximately 1 min.
Experimental task: Approach left-side virtual, then across front of virtual human to right side, then to front to read a Likert-type scale positioned over virtual human's head. (Social presence and affect questionnaires administered at this time.) Return to starting point and stand while approached by virtual human. Virtual human moved through participant. 2 blocks of 5 trials, each trial 5 to 10 min. (Emotional reaction questionnaire administered.)
Participants: 80 introductory psychology students; age range 18 to 25; mean age 19.6 years.
Study design: Within-subject for virtual human; between-subjects for gaze behavior, participant gender, and agency.
Presence measures: 5-item social presence questionnaire, minimum interpersonal distance.
Task-related measures: Affect rating for avatar, emotional reaction questionnaire (used as co-markers for co-presence).
Findings:
(1) A male virtual human was significantly associated with higher social presence scores. Virtual human gender had a significant interaction with agency, with more presence reported for male avatars.
(2) Mutual gaze behavior was associated with significantly higher social presence scores. Gaze behavior had a significant interaction with participant gender, with more presence reported by male participants.
(3) An avatar was associated with significantly higher social presence scores.

(4) Contact time had a significant relationship with minimum interpersonal distance, with greater distances left after the virtual human passed through the participant.
(5) Participant gender had no significant relationship with social presence.
(6) An agent was associated with a significantly larger interpersonal distance than an avatar. Virtual human gender, gaze behavior, and participant gender had no significant relationship with minimum interpersonal distance.
(7) Virtual human gender, gaze behavior, participant gender, and agency had no significant relationship with liking of virtual human.
(8) Emotional reaction scores had a significant positive correlation with maximum avoidance distance.

[Bailenson 2002] Bailenson, J. N., Beall, A. C., and Blascovich, J. (2002). Gaze and task performance in shared virtual environments. *Journal of Visualization and Computer Animation, 13,* 313–320.

Factors:		Behavioral realism (mutual gaze, no head movement, no avatar).
Computing platform:		450-MHz Intel Pentium III with dual processors, Evans and Sutherland Tornado 3000 graphics cards.
Visual display:		Three Virtual Research V8 stereoscopic HMDs with 680 × 480 resolution, 60º diagonal FOV, 36-Hz frames per second (fps) rate with latency < 65 ms.
Audio display:		Auditory headset worn over HMD, with microphone.
Tracking:		Head tracking.
Navigation:		None.
Object manipulation:		None.
Virtual world:		Room where three participants met around a common table. Avatar head movements were used to show direction of participants' gaze and were accompanied by blinking and mouth movements. Participants unable to see own avatar.
Experimental task:		In groups of three, play "20 questions" game. One participant in each trial always the answerer, with the other two asking questions. 3 blocks of 3 trials (questionnaire completed after each block).
Participants:		27 undergraduate psychology students; 16 males.
Study design:		Within-subjects.
Presence measures:		10-item presence questionnaire including 3 items on social presence.
Task-related measures:		*Average time individual participants spent speaking, head orientation*.
Performance measures:		*Number of questions asked per game, average time to finish a game*.
Findings:	(1)	Behavioral realism had a significant relationship with total questionnaire scores and on 2 social presence items, with most presence reported for the more realistic avatars.
	(2)	*Behavioral realism had a significant relationship with time participants spent speaking, with least speaking with more realistic avatars and more speaking when no avatars. However, had no significant relationship with number of questions asked or average time to finish a game.*
	(3)	*Behavioral realism had no significant relationship with head orientation.*

[Bailenson 2001a] Bailenson, J. N., Blascovich, J., Beall, A. C., and Loomis, J. M. (2001a). Equilibrium theory revisited: Mutual gaze and personal space in virtual environments. *Presence, 10* (6), 583–598.

Factors:	Character realism (photographic texturing face, flat shaded face), behavioral realism (mutual gaze with eye dilation when participant stepped within 0.75 m, mutual gaze, eyes open and blinking, eyes open, eyes closed), participant gender (male, female).
Computing platform:	450-MHz Pentium III with dual processors, with Evans and Sutherland Tornado 3000 dual-pipe graphics card. System latency < 65 ms.
Visual display:	Virtual Research V8 stereoscopic HMD with resolution 680 × 480, FOV 50º H × 38ºV. Frame rate 36 Hz. Participant eye height used to adjust display.

Tracking:	Head tracking using InterSense IS-300 and in-house passive optical position sensing system.
Navigation:	Walking around.
Object manipulation:	None.
Virtual world:	7.2 × 6.4 × 4.5 m room with either a pylon or an agent standing inside. Agent represented as a Caucasian male, 3D polygonal model, 1.85 m tall, and wearing a label on the front of his shirt giving his name and a back label listing a number, both in text easily readable from 1 m. Different colored shirt and hair, and different name and number for each trial. Mutual gaze included periodic blinking. No collision detection. No self-representation. In control condition, a pylon replaced the agent, same height as agent, with color and labels changing. 2 blocks of 5 trials, with each block taking 5 to 15 min.
Training:	Walking round empty virtual room for approximately 1 min.
Experimental task:	Walk toward agent and read number on back of shirt, then name on front. After completing recall test, participant redonned HMD to complete social presence questionnaire while in virtual world.
Participants:	50 participants; 26 males; age range 18 to 31. Ten participants used in control condition with pylon.
Study design:	Within-subjects for face model, between-subjects for gaze behavior, gender.
Presence measures:	5-item social presence questionnaire, minimum interpersonal distance.
Person-related meas.:	Gender.
Performance measures:	*Percent correct when matching of names to numbers for recall test. (Results almost identical to those for minimum interpersonal distance; also highly correlated with minimum interpersonal distance.)*

Findings:

(1) Character realism and gender had no significant relationship with social presence (excluding control condition).

(2) Behavioral realism had a significant relationship with social presence for females only, with more presence reported for mutual gaze.

(3) Participants in the agent condition left a significantly larger interpersonal distance. Gender had a significant interaction effect with character realism on interpersonal distance, with females maintaining more distance when agents used mutual gaze.

(4) Behavioral realism had a significant relationship with minimum interpersonal distance for females only, with more distance left more distance for a mutual gaze.

(5) Character realism had a significant relationship with memory test scores when the control condition was considered, with the pylon giving better scores.

(6) Realism of face model, behavioral realism, and gender had no significant relationship with memory test scores.

[Bailenson 2001b (1)] Bailenson, J. N., Beall, A. C., Blascovich, J., Raimundo, M., and Weisbuch, M. (2001b). Intelligent agents who wear your face: users' reactions to the virtual self. *Proceedings of the 3rd International Workshop on Intelligent Virtual Agents,* Madrid, Spain, September, 86–99.

Factors:	Agency (avatar of self, avatar of other).
Computing platform:	450-MHz Intel Pentium III PC with dual-processor, with Evans and Sutherland Torndao 3000 video adapter. OpenGL-based software rendering.
Visual display:	Virtual Research V8 stereoscopic HMD with 680 × 480 resolution, FOV 60° diagonal. Frame rate 36 Hz, with latency < 65 ms.
Audio display:	None.
Tracking:	Orientation and position tracking.
Navigation:	Walking in 3 × 3 m area.
Object manipulation:	None.
Virtual world:	Open area containing an avatar with a detailed head and generic body covered by a loose robe. Avatars had head movements and blinking eyes. Virtual eye height set to 1.7 m.

Experimental task:	Walk to the left side of the embodied agent, then to the right side, and then to the front of the agent.
Participants:	16 introductory psychology students.
Study design:	Between-subjects.
Presence measures:	6-item social presence questionnaire, minimum distance in approaching agent.
Task-related measures:	Affect rating for avatar, willingness to perform embarrassing actions rating (used as co-markers for co-presence).
Findings: (1)	Agency had no significant relationship with social presence.
(2)	An avatar of self was associated with a significantly smaller minimum distance.
(3)	Agency had no significant relationship with affect rating; an avatar of self was associated with significantly more willingness to perform an embarrassing action.

[Bailey 1994 (2)] Bailey, J. H., and Witmer, B. G. (1994). Learning and transfer of spatial knowledge in a virtual environment. *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting*, Nashville, USA, October, 1158–1162.

Factors:	Training type (exploratory, restrictive), head tracking (present, absent).
Computing platform:	SGI Crimson Reality Engine. Software Systems Multigen and Sense8 Corporation WorldToolKit.
Visual display:	Stereoscopic, color Virtual Reality Flight Helmet.
Tracking:	Head tracking.
Navigation:	Using standard video game joystick.
Object manipulation:	None.
Virtual world:	Building.
Training:	None.
Experimental task:	3 rehearsals of circuitous route in VE using instructional strategy either based on finding and following successive landmarks (exploratory) or following left/right style directions (restrictive). Participants tested in actual building.
Participants:	64 participants; 32 males.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 2.0.
Person-related meas.:	Witmer-Singer 29-item ITQ Version 2.0.
Task-related measures:	Kennedy SSQ.
Performance measures:	Route knowledge: time taken to complete rehearsal, time spent in decision areas, time in stairways, number of collisions, time spent in collisions, time spent looking at landmarks, attempted number of attempted wrong turns, distance traveled, scores on ordering route photographs. Building configuration knowledge: measured using paper-based and cathode ray tube (CRT)-based projection convergence technique for triangulating 4 targets from 3 sighting locations.
Findings: (1)	Training type and head tracking had no significant relationship with presence.
(2)	ITQ scores had a significant positive correlation with presence.
(3)	Simulator sickness had a significant negative correlation with presence.
(4)	Route knowledge only as assessed by photograph ordering test had a significant positive correlation with presence.
(5)	Configuration knowledge only as assessed by accuracy on paper convergence test had a significant positive correlation with presence.
(6)	*Exploratory training was associated with significantly better scores in route photograph ordering.*
(7)	*Restrictive training was associated with significantly less time taken (using only participants who did not experience simulator sickness) and significantly more wrong turns.*
(8)	*Head tracking had a significant interaction with training type, such that restricted participants learned the configuration best without head tracking, also a significant relationship with rate of learning showing less time.*

(9) *Rehearsal trial had a significant negative relationship with time spent in decision areas, time to complete rehearsal, time in stairways, time spent looking at landmarks, and number of attempted wrong turns.*

(10) *ITQ scores had no significant correlation with any performance measure.*

(11) *SSQ scores had a significant positive correlation with route completion time and CRT-based projective convergence test and a significant negative correlation with photo-ordering accuracy.*

[Baños 2005] Baños, R. M., Botella, C., Guerrero, B., Liaño, V., Alcañiz, M., and Rey, B. (2005). The third pole of the sense of presence: comparing virtual and imagery spaces. *PsychNology Journal, 3* (1), 90–100.

Factors:	Environment type (VR Mood Induction Procedure (MIP), imagery MIP)).
Visual display:	Projection screen, projector with 1024 × 768 pixels and 2,000 lumens (regulated to 1,000 lumens for the experiment).
Navigation:	Joystick.
Object manipulation:	Joystick.
Virtual world:	A park with open areas and walkways, trees, benches, light stand, and a bandstand. Initially, the park was the same for all emotional conditions (sadness, happiness, anxiety, and relaxation) and then changed depending on the emotional condition. A woman's voice guided participants in walking through the park. Music was heard throughout. MIPs included a short history and the content of Velten statements displayed in a disordered manner on the sides of a bandstand, movies, pictures, and music.
Experimental task:	Listen to short history according to the emotional condition. Then 2 min of free exploration in the virtual park followed by instruction to visit the bandstand and order the statements, select 1 of 4 pictures that best represents meaning of statements. Asked to get involved in the contents of each sentence for 45 sec, to think about the personal meaning of each statement. Then walk around the park for another 2 min and go to the cinema to watch a short film. Once the cinema session finished, participants were asked to tell in a loud voice a personal recollection similar to the things that happened in the park. For the imagery MIP, participants were asked to create an imaginary environment where the same elements were included by, for example, looking at pieces of paper and switching on a movie at appropriate points.
Participants:	100 participants; 37 males; age range 18 to 41; mean age 22.83 years. Inclusion criteria: nonhistory of neurological disease, head injury, learning disability or mental disorder; nonhistory of psychological disorders; non-use of any mediation for psychological or emotional problem; and scoring lower than 18 in Beck Inventory Depression.
Study design:	Between-subjects.
Presence measures:	UCL Presence Questionnaire, and variations on 1st and 3rd questions asked during virtual and imagined environments at the beginning, in the middle of the experience, at the end.
Findings: (1)	Presence had a significant interaction with moment, such that Presence and Reality Judgment for the VR participants showed an increase in the "sense of being there" and "reality attribution," whereas the participants in the imagery condition gave scores with the opposite pattern.
(2)	VR participants gave significantly higher scores for realism.

[Baños 2004] Baños, R. M., Botella, C., Alcañiz, M., Liaño, V., Guerrero, B., and Rey, B. (2004). Immersion and emotion: their impact on the sense of presence. *CyberPscyhology, 7* (6), 734–741.

Factors:	Emotion (sadness, neutral), visual display (HMD, rear projection screen, desktop).
Computing Platform:	PC-based computers with high-end graphics capability.

Visual display:		Fifth Dimension Technologies (5DT) model 800 HMD, 400 × 150 cm rear projection video wall, 17-in. desktop monitor.
Tracking:		Head tracking using InterSense InterTrax2.
Navigation:		Using joystick.
Object manipulation:		Using joystick.
Virtual world:		One virtual world consisted of a park scenario designed to induce a sense of sadness using MIPs with music, narratives, Velten self-statements, pictures, movies, and autobiographical recalls.
Training:		Practice in a training virtual world.
Experimental task:		Free exploration of park for 2 min. Then, go to bandstand and order a disordered statement while getting involved in the contents of each sentence. Then, navigate around park for another 2 min. Go to cinema and watch movie and then produce an autobiographical recall.
Participants:		60 university participants; 23 males; age range 18 to 49; mean age 24.8 years. No history of neurological disease, head injury, learning disability, mental disorders, or psychological disorders, and non-use of medications for psychological or emotional problems, and scores lower than 18 in the Beck Depression Inventory.
Study design:		Between-groups.
Presence measures:		Independent Television Commission-Sense of Presence Inventory (ITC-SOPI), 29-item version of Reality Judgment and Presence Questionnaire (RJPQ).
Findings:	(1)	Participants in the sad virtual world reported significantly higher scores for ITC-SOPI subscales for Engagement and Ecological Validity.
	(2)	Participants in the sad virtual world reported significantly higher scores for RJPQ subscales for Reality Judgment and Emotional Engagement, and emotion had a significant relationship with RJPQ Emotional Indifference subscale with participants in the neutral virtual world reporting more presence.
	(3)	HMD participants reported significantly ITC-SOPI scores than rear projection screen or desktop-monitor participants.
	(4)	Rear-projection-screen participants reported significantly higher scores for RJPQ Quality/Realism and Interaction/Navigation subscales.
	(5)	An interaction effect for emotion and display type was found for ITC-SOPI Engagement and Ecological Validity subscales, with those in the sad group reporting more presence.

[Barfield 1998] Barfield, W., Baird, K. M., and Bjorneseth, O. J. (1998). Presence in Virtual environments as a function of type of input device and display update rate. *Displays, 19* (2), 91–98.

Factors:	Update rate (20, 15, 10 Hz), navigation (3 DOF joystick, 3 DOF SpaceBall).
Computing platform:	SGI Indigo Extreme R4400 graphics workstation. In-house software with objects designed using Lambertian-shaded[2] 4-sided polygons of different shapes and sizes. Gouraud shading and ambient light model.
Visual display:	GE-610 6 × 8 ft rear projection screen, stereoscopic viewing using StereoGraphics Corporation CrystalEyes shutter glasses. Imagery generated at 1280 × 512 pixel resolution, 70º FOV and geometric field of view (GFOV). Eyepoint elevation 110 cm. Subject seated.
Navigation:	Measurement Systems Inc. Model 544 3 DOF joystick or Spatial Systems SpaceBall Model 1003 3 DOF spaceball.
Object manipulation:	None.

[2] If a surface exhibits Lambertian reflectance, light falling on it is scattered such that the apparent brightness of the surface to an observer is the same regardless of the observer's angle of view. More technically, the surface luminance is the same regardless of angle of view. Lambertian reflectance is named after Johann Heinrich Lambert (1728–1777), a German mathematician, physicist, and astronomer.

Virtual world:		Virtual Stonehenge in a night setting. Menhirs constructed of 4- and 6-sided polygons of different sizes and shapes. Ground was green, sky navy blue with stars, Stonehenge edifices beige. Passive ambient night sounds.
Training:		Two 4-min training sessions in Virtual Stonehenge.
Experimental task:		Navigate site and search for a rune inscribed on one side of a menhir. 12 trials. 2-min time limit.
Participants:		8 participants; 5 males; mean age 30 years.
Study design:		Within-subjects.
Presence measures:		18-item presence questionnaire, questions categorized as (1) presence, (2) engagement of senses in virtual world, and (3) fidelity of interaction.
Findings:	(1)	Update rate had a significant effect for 13 items on presence questionnaire, with more presence reported for 15 or 20 Hz than for 10 Hz.
	(2)	Navigation device had no significant relationship with presence.

[Barfield 1995] Barfield, W., and Hendrix, C. (1995). The effect of update rate on the sense of presence within virtual environments. *Human Factors, 1* (1), 3–16.

Factors:		Update rate (25, 20, 15, 10, 5 Hz).
Computing platform:		SGI Indigo Extreme workstation. Objects Lambertian shaded, designed using 4-sided polygons of difference shapes and sizes.
Visual display:		GE-610 6 × 8 ft rear projection screen, stereoscopic viewing using StereoGraphics Corporation CrystalEyes shutter glasses. Imagery generated with 1280 × 512 pixel resolution, GFOV 50º. Eyepoint elevation 110 cm. Subject seated with 90º FOV of screen. Black curtain to isolate viewing area.
Tracking:		Polhemus 3Space FASTRAK for head tracking.
Navigation:		3 DOF flight stick located on table in front of participant.
Object manipulation:		None.
Virtual world:		Virtual Stonehenge (see [Barfield 1998]).
Training:		10 practice trials in the VE.
Experimental task:		Navigate site and search for a rune inscribed on a wall. 12 trials. 2-min time limit.
Participants:		13 participants; 9 males; mean age 25.3 years.
Study design:		Within-subjects.
Presence measures:		13-item Barfield's presence questionnaire, including overall rating question; questions categorized as (1) presence and (2) fidelity of interaction.
Findings:	(1)	Update rate had a significant relationship with presence, with less reported presence for 5 and 10 Hz than for 20 and 25 Hz when considering overall presence rating and 3 other questions directly related to presence. No significant difference for presence items related to awareness of the real world or simulation speed.
	(2)	Fidelity of interaction had a significant positive correlation with presence.
	(3)	Update rate had a significant relationship with fidelity of interaction for all items, with increased fidelity for 20 to 25 Hz compared with 5 Hz.

[Barfield 1993 (1)] Barfield, W., and Weghorst, S. (1993). The sense of presence within virtual environments: A conceptual framework. In G. Salvendy and M. J. Smith (Eds.), *Human-Computer Interaction: Software and Hardware Interfaces* (pp. 699–704). New York: Elsevier.

Visual display:	VPL EyePhones.
Tracking:	Polhemus six-dimensional (6D) tracker for hand tracking.
Navigation:	VPL DataGlove.
Object manipulation:	None.
Virtual world:	Two virtual worlds—(1) Virtual Seattle and (2) three similarly complex environments—differing in their use of a ground plane and other spatial landmarks and in the visibility and degree of abstractness of objects.
Experimental task:	Navigating through two virtual worlds.

Participants:		86 participants; age range 14 to 59.
Presence measures:		3 items of 24-item questionnaire.
Person-related meas.:		Age, introspection, comfort with computers.
Task-related measures:		Ratings of enjoyment, engagement, ease of navigation, display comfort, being lost, display color quality, image clarity, movement ease, orientation in VE.
Findings:	(1)	Enjoyment had a significant positive correlation with each of "sense of being there," "sense of inclusion in the virtual world," and "sense of presence in the virtual world."
	(2)	Age had a significant negative correlation with "sense of inclusion in the virtual world."
	(3)	(In order of decreasing strength) display comfort, comfort with computers, ease of navigation, being lost, overall enjoyment, display color quality, and ability to get around had a significant positive correlation with "sense of being there."
	(4)	(In order of decreasing strength) overall enjoyment, overall comfort, introspection, ease of interaction, ease of navigation, and movement ease had a significant positive correlation with "sense of inclusion."
	(5)	(In order of decreasing strength) orientation within the virtual world, being lost, engagement, color quality, image clarity, overall enjoyment, and ability to get around had a significant positive correlation with "sense of presence."

[Barfield 1993 (2)] Barfield, W., and Weghorst, S. (1993). The sense of presence within virtual environments: A conceptual framework. In G. Salvendy and M. J. Smith (Eds.), *Human-Computer Interaction: Software and Hardware Interfaces* (pp. 699–704). New York: Elsevier.

Visual display:		VPL EyePhones.
Tracking:		Polhemus 6D tracker for hand tracking.
Navigation:		Joystick handle with embedded tracker.
Object manipulation:		None.
Virtual world:		Various simple VEs.
Experimental task:		Designing 3D model and object dynamics for a VE, then navigating, exploring, and interacting with implemented VE.
Participants:		69 participants; age range 8 to 16; mean age 11.8 years.
Presence measures:		2 items of 27-item questionnaire.
Task-related measures:		Enjoyment of camp, enjoyment of designing/building a virtual world.
Findings:	(1)	Enjoyment of designing and building a virtual world had a significant positive correlation with "feeling part of the virtual world."
	(2)	Enjoyment of the technology camp had a significant positive correlation with "feeling part of the virtual world."

[Basdogan 2000] Basdogan, C., Ho, C.-H., Srinivasan, M. A., and Slater, M. (1998). An experimental study on the role of touch in shared virtual environments. *ACM Transactions on Computer Human Interactions, 7* (4), 443–460. See also Ho, C., Basdogan, C., Slater, M., Durlach, N., and Srinivasan, M. A. (1998). An experiment on the influence of haptic communication on the sense of being together. Available: http://www.cs.ucl.ac.uk/staff/m.slater/BTWorkshop/TouchExp/index.html

Factors:	Haptic force feedback (present, absent).
Computing platform:	IBM-compatible 300-MHz PC with dual Pentium II processors, 3D graphics accelerator. Open Inventor rendering software for visual display, in-house software for haptic rendering.
Visual display:	Two monitors.
Haptic display:	Two SensAble Technologies PHANTOM devices, each providing force feedback to a single finger, haptic update rate 1 kHz.

Object manipulation:	PHANTOMs slaved to ring, with each contact point represented by a cursor positioned on the ring. Both partners press on the ring at the same time to hold it and move it.
Virtual world:	World consisted of bent wire strung between two end points. Ring positioned loosely over wire with blue/green cursors to denote participants' contact points. Background of two walls positioned to form a back wall and floor. Wire and ring cast a shadow on the floor.
Experimental task:	Work with a remote partner (the same expert user expected to exhibit constant performance across trials) to move a ring back and forth along a wire while minimizing or avoiding contact between the wire and the ring. Contact between wire and ring denoted by ring color and surrounding walls changing color.
Participants:	10 participants.
Study design:	Within-subjects.
Presence measures:	8-item co-presence questionnaire.
Person-related meas.:	Social anxiety, age, gender, computer use.
Task-related measures:	Social anxiety assessment of partner.
Performance measures:	Proportion of time ring was not intersecting the wire.
Findings: (1)	Haptic force feedback was associated with significantly higher co-presence scores.
(2)	Females reported significantly higher co-presence scores.
(3)	Age had a significant negative correlation with co-presence, and computer use had a significant positive correlation with co-presence.
(4)	Participant's social anxiety had a significant relationship with co-presence: negative for males, positive for females.
(5)	Extent of social anxiety of partner had a significant positive correlation with co-presence.
(6)	Task performance had a significant positive correlation with co-presence for the haptic force feedback condition only.
(7)	*Haptic feedback was associated with significantly increased time that ring was not in connection with wire.*
(8)	*Group had a significant interaction with condition, such that use of the visual system only first, followed by the visual and haptic system, resulted in better performance than the reverse order.*

[Baumgartner 2006] Baumgartner, T., Valko, L., Esslen, M., and Jäncke, L. (2006). Neural correlate of spatial presence in an arousing and noninteractive virtual reality: An EEG and psychophysiology study. *CyberPsychology & Behavior, 9* (1), 30–45.

Visual display:	17-in. desktop monitor.
Auditory display:	Headphones.
Tracking:	None.
Navigation:	None.
Object manipulation:	None.
Virtual world:	5 roller coaster scenarios (taken from commercially available roller coaster simulations). Realistic rides, including spectacular ups and downs. Realistic driving noises. Perspective as if seated in the front seat of the roller coaster cab. Each experimental scenario divided into 3 sessions:(1) initial upward driving, mean duration 40 sec, (2) dynamic upward and downward driving, mean duration 63 sec, and (3) final horizontal drive of cab, duration 28 sec.
Experimental task:	During initial phase (control session), participant experienced a horizontal roundabout track without any up/down movements, duration 120 sec. During experimental sessions, experienced other scenarios.
Participants:	(1) 12 children; 5 males; age range 8.4 to 10.7; mean age 9.2 years, and (2) 11 adolescents; 7 males; age range 13.9 to 17.9; mean age 15.8 years. All right-handed. None had reported any neurological or psychiatric disease, prior head trauma, sensory impairment, or subjective cognitive impairment.

Presence measures: Measures, Effects, Conditions-Spatial Presence Questionnaire (MEC-SPQ), EEG, skin conductance, heart rate.

Findings:

(1) Children and adolescents both gave significantly higher MEC-SPQ scores for the roller coaster ride (experimental versus control). Children's scores were significantly higher than adolescents.

(2) Roller coaster ride had a significant relationship with skin conductance with more skin conductance sum amplitude for the initial upward driving sessions than the dynamic part, which was more than the final horizontal drive.

(3) Skin conductance amplitude during the dynamic part of the rides had a significant positive correlation with MEC-SPQ Self-Location scores.

(4) Roller coaster ride had no significant relationship with heart-rate measures.

[Bennett 2006 (1)] Bennett, E., and Stevens, B. (2006). The effect that the visual and haptic problems associated with touching a projection augmented model have on object presence. *Presence, 15* (4), 419–437.

Factors: Projection direction (front-projected, back-projected), feel to touch (feels correct, feels incorrect, no touch).

Visual display: Using XGA resolution projectors, one projected down from 45º angle, one from 45º angle from below.

Virtual world: 4 projection augmented views, each consisting of 7 compact disc (CD) cases.

Experimental task: To focus participants' attention on the task, they were told the experiment was investigating how Projection Augmented (PA) models can assist product design.

Part 1: On one PA model, touch each CD case (being told this was required to calibrate the hand tracking device) and then touch a CD case to indicate their preference for the design on the sleeve. Those in the no touch condition were asked to just look at the CD cases and indicate their selection by speaking the number on the selected case. All were asked to categorize the 7 CD cases into two groups based on the ones they thought were similar in some way (measure 1) and then those they would describe as sticky and those they would describe as smooth (measure 2). After facing away from the display, participants were asked to describe their main memory of the design system (measure 3) and main memory of what they saw (measure 4). The object-presence questionnaire was measure 5.

Part 2: Using all PA models simultaneously, complete another design task (related to their preference for color) that entailed touching all l28 CD cases. Then, asked to put the 4 sets in order based on their sense of object presence (measure 6), decide whether touching the cases increased or decreased the sense of object presence (measure 7), determine which set(s) gave strongest sense that the paper sleeve was inside the CD case (measure 8), decide which set(s) gave strongest impression that images were printed on the paper sleeves (measure 9), and, after facing away from the PA models, answer whether they have noticed the projected image on their hands, the shadows, and how the CD cases felt to touch (measure 10).

Participants: 50 students in computing-related degree courses.

Study design: Between-subjects for Part 1 and within-subjects for Part 2.

Presence measures: 7-item object presence questionnaire.

Findings:

(1) For measure 5: projection direction was not related to any significant difference in object-presence scores.

(2) For measure 5: feel to touch had a significant relationship with 3 (of 7) items on object presence questionnaire.

(3) For measure 6: projection direction had no significant relationship with responses.

(4) For measure 6: feel to touch had a significant relationship with responses.

[Bennett 2006 (2)] Bennett, E., and Stevens, B. (2006). The effect that the visual and haptic problems associated with touching a projection augmented model have on object presence. *Presence, 15* (4), 419–437.

Factors:		Projection direction (front-projected, back-projected), feel to touch (feels correct, feels incorrect).
Computing platform…		
Visual display:		As in [Bennett 2006 (1)].
Virtual world:		4 PA views, each consisting of a 6 different colored vodka jellies (actually made from gel candle wax set into shot glasses).
Experimental task:		As in [Bennett 2006 (1)], except measures 1 and 2 not used.
Participants:		As in [Bennett 2006 (1)].
Study design:		As in [Bennett 2006 (1)].
Presence measures:		6-item object presence questionnaire.
Findings:	(1)	For measure 5: significant effects were found for questions 2 and 6.
	(2)	For measure 6: projection direction had no significant relationship with responses.
	(3)	For measure 6: feel to touch had a significant relationship with responses.

[Bente 2004] Bente, G., Rüggenberg, S., and Krämer, N. C. (2004).Social presence and interpersonal trust in avatar-based, collaborative net-communications. *Proceedings of the 7th Annual International Workshop on Presence,* Valencia, Spain, October, 54–61.

Factors:		Communication modality [face-to-face video, avatar-based virtual video conference (VVC), text-based chat, audio phone communication)].
Computing platform:		ABC-desk (an avatar-based collaborative desktop environment) CVE that allows handling same objects. Data transmitted over Intranet [Transmission Control Protocol/Internet Protocol (TCP-IP)]. Avatars rendered by Kaydara Filmbox.
Visual display:		Desktop monitors.
Tracking:		Eye-tracking, Cybergloves used for nonverbal behaviors.
Navigation:		None.
Object manipulation:		None.
Virtual world:		Interaction partner presented as an animated avatar.
Experimental task:		Collaborative problem-solving task where participants were required to select a new employee for a certain job. 5 to 10 min.
Participants:		48 students working in same-sex pairs with an experimenter.
Study design:		Between-subjects.
Presence measures:		58-item social presence questionnaire based on Biocca's questionnaire, with co-presence, comprehension, connectedness, contingency, and closeness subscales.
Task-related measures:		20-item interpersonal trust questionnaire with cognitively based trust and affectively based trust components.
Findings:	(1)	Participants in the face-to-face modality gave significantly higher social presence co-presence scores than participants in other conditions. Participants in the audio phone modality gave significantly higher social presence. Participants in the avatar-based VVC modality gave significantly higher social presence comprehension scores than other participants.
	(2)	Participants in the face-to-face and audio phone modalities gave significantly higher cognitively based trust scores than participants in the avatar-based VVC modality.
	(3)	Cognitively based interpersonal trust had a significant negative correlation with social presence comprehension.
	(4)	Affectively used interpersonal trust had a significant positive correlation with social presence closeness.

[Biocca 2001] Biocca, F., Kim, J., and Choi, Y. (2001). Visual touch in virtual environments: An exploratory study of presence, multimodal interfaces, and cross-modal sensory illusions. *Presence*, *10* (3), 247–265.

Computing platform:	SGI Onyx Reality Engine with 2 graphics pipes. Software Systems Multigen Smart Scene software.
Visual display:	Stereoscopic Virtual Research V8 HMD.
Tracking:	Polhemus magnetic tracking for head and hands.
Object manipulation:	Fakespace Labs pinch gloves for using gestures to grab and move objects. A visual representation of a spring indicated that an object was being pulled away from its "snap" position. When pulled far enough, the spring was retracted, and the object "popped" into participant's hand.
Virtual world:	Environment 1: Media Interface and Network Design (M.I.N.D.) Lab's Virtual Hands-on Cadaver Environment; 3D room resembling a doctor's examining room, with examining table with a cadaver (realistic skeleton with 8 complete organs in rib cage) and medical charts on the wall. Environment 2: Similar to first environment but with a collection of simple symmetrical polygonal shapes occupying the same space and location of the cadaver, matching the number of objects in the virtual cadaver. Hands represented as 3D cursors (blue transparent sphere with embedded tubular cross).
Training:	View recorded training session to provide basic instructions in how to navigate the environment and manipulate objects. Participants spent time in a training VE (an open city space) until they felt comfortable with that environment.
Experimental task:	In the experimental environment: remove all organs from the cadaver. In the control environment, remove symmetrical objects.
Participants:	77 university students.
Presence measures:	Questionnaire.
Task-related measures:	Cross-modal visual-to-haptic and visual-to-aural illusions.
Findings: (1)	Reports of cross-modal visual-to-haptic illusions had a significant positive correlation with presence.
(2)	Reports of cross-modal visual-to-aural illusions had no significant correlation with presence.

[Böcking 2004] Böcking, S., Gysbers, A., Wirth, W., Klimmt, C., Hartmann, T., Schramm, H., Laarni, J., Sacau, A., andVorderer, P. (2004). Theoretical and empirical support for distinctions between components and conditions of social presence. *Proceedings of the 7th Annual International Workshop on Presence*, Valencia, Spain, October, 224–231.

Factors:	Environment type (VE, hypertext, film, linear text), dual task (secondary task, no secondary task).
Virtual world:	VE was *Musee d'Orsy in Paris* exhibition of 19th Century art. Hypertext was *The Art of Singing* 2D virtual academy of song. Film was sequence from *Das Boot—Director's Cut*. Linear text was extract out of *The Pillars of the Earth* by Ken Follett.
Experimental task:	Explore presentation. Depending on condition, dual task required generation of random numbers.
Participants:	290 students from the United States, Portugal, Finland (49 in VE condition); ~ 25% males; age range 15 to 54; mean age 21.4 years. VE and hypertext, individually. Film and text, in groups of 6 to 7.
Study design:	Within-subjects for environment type and between-subjects for dual task.
Presence measures:	MEC-SPQ.
Findings: (1)	Participants who had the secondary task reported significantly lower presence on MEC-SPQ Self-Location, Possible Actions, and Involvement subscales.

	(2)	Self-Location scores had a significant positive correlation with Possible Actions scores. Involvement scores had a significant positive correlation with Self-Location and Possible Actions.

[Borman 2005 (1)] Borman, K. (2005). Presence and the utility of audio spatialization. *Presence, 14* (3), 278–297. See Borman 2005 (2) for comparison of results.

Factors:		Audio cues (spatialized, directional, and nonattenuated).
Computing platform:		SGI O2 workstations running Distributed Interactive Virtual Environment (DIVE) 3.3 software. Spatialization performed by DIVE system with other standard audio default settings and with respect to participant's avatar.
Visual display:		20-in. desktop monitor with 1280 × 1024 resolution, physical FOV 40º horizontal, frame rate 12±2 fps.
Auditory display:		Labtec LVA8550 headphones, audio source captured in 16-bit stereo.
Tracking:		None.
Navigation:		Keyboard and arrow keys.
Object manipulation:		Using keyboard.
Virtual world:		*WhoDo mansion* originally constructed for a Collaborative Virtual Environments (COVEN) project. Normal-sized house with hall connecting several furnished rooms. Overall, 10 rooms, 9 containing a domino.
Experimental task:		Search task disguised as domino game. Participant asked to find dominos in order, starting with the one placed in the room where the participant is present at onset. To mark a domino as found, participant moves it slightly (only the next domino in the order can move). Game started by clicking on the radio present in central room.
Participants:		19 participants; 15 males; age range 20 to 47.
Study design:		Between-subjects.
Presence measures:		4-item Slater-Usoh-Steed (SUS) Questionnaire, 18-item-Witmer-Singer PQ.
Person-related meas.:		Subset of Witmer-Singer Immersive Tendencies Questionnaire.
Task-related measures:		1 item related to mastery of interface (also addressed by 4 PQ items), *4 items related to spatial acquisition*.
Performance measures:		Time taken.
Findings:	(1)	Based on change scores across the 2 experiments, participants who had spatialized audio cues gave significantly higher SUS Questionnaire scores. Audio cues had no significant relationship with PQ scores.
	(2)	SUS Questionnaire and PQ scores had a significant positive correlation.
	(3)	*Audio cues had no significant relationship with time taken.*
	(4)	*Sum of scores on items relating to mastery of the interface had no significant association with time taken.*

[Borman 2005 (2)] Borman, K. (2005). Presence and the utility of audio spatialization. *Presence, 14* (3), 278–297.

Factors:	Audio cues (spatialized, directional, and nonattenuated), audio utility (relevant to task, not relevant).
Computing platform…	
Object manipulation:	As in [Borman 2005 (1)].
Virtual world:	Structure consisting of 19 hexagonal white rooms, all empty except for central room. Central room had 2 pedestals: one holding a pink ball, the other holding a radio. Either the ball or the radio assumed the role of the hyperball. Game was started by clicking on the radio. Then the hyperball moves (within sight) into another room. When clicked on, the hyperball moved again. Continued for 12 searches.
Experimental task:	Search task disguised as hyperball game.
Participants:	Same as [Borman 2005 (1)].

Study design: Between-subjects.
Presence measures…
Performance measures: As in [Borman 2005 (1)].

Findings:
(1) Based on change scores across the 2 experiments, participants with nonattentuated audio cues gave significantly higher SUS Questionnaire scores. Audio cues had no significant relationship with PQ scores.
(2) Based on change scores across the 2 experiments, participants with audio relevant to the task gave significantly higher PQ scores. Audio utility had no significant relationship with SUS Questionnaire scores.
(3) Based on change scores across the 2 experiments, SUS Questionnaires and PQ scores had no significant correlation with time taken.
(4) Based on change scores across the 2 experiments, PQ scores had a significant positive correlation with perceived performance (mastery of interface), unlike SUS Questionnaire scores.
(5) Spatial acquisition scores had a significant positive correlation with PQ scores, unlike SUS Questionnaire scores.
(6) SUS Questionnaire and PQ scores had a significant positive correlation.
(7) Audio cues had no significant relationship with time taken.
(8) Audio utility had no significant relationship with time taken.
(9) Sum of scores on items relating to mastery of the interface had no significant association with time taken.
(10) Participants who had the radio hyperball gave significantly higher ratings for auditory involvement than participants gave for the domino game.
(11) Participants who had the radio hyperball gave significantly lower ratings for visual involvement than those who had a ball hyperball and for the domino game.

[Botella 1999] Botella, C., Rey, A., Perpiñà, C., Baños, R., Alcañiz, M., Garcia-Palacios, A., Villa, H., and Lozano, J. A. (1999). Differences in presence and reality judgment using a high impact workstation and a PC workstation. *CyberPsychology & Behavior, 2* (1), 49–52.

Factors: Level of equipment (SGI with FS5 HMD and 3D joystick, Pentium II with V6 HMD and 2D mouse).
Computing platform: SGI high impact computer graphics workstation with Division's dVise software or Pentium II-based workstation with AccelEclipse Graphical Card with Sense8 WorldUp software.
Visual display: High-quality Virtual Research FS5 HMD or medium-quality Virtual Research V6 HMD.
Navigation: Using a Division 3D joystick or standard 2D mouse.
Virtual world: Designed for treatment of claustrophobia. Consisted of a room where participants could walk and open/close windows and doors, and a second smaller room where participants could walk and open/close the door and move one of the walls to narrow room dimensions.
Experimental task: 15-min exposure.
Participants: 69 undergraduates; age range 19 to 35.
Study design: Between-subjects.
Presence measures: 15-item Reality Judgment and Presence Questionnaire.

Findings:
(1) Level of equipment had no significant relationship with presence or reality judgment.

[Bouchard 2006] Bouchard, S., Dumoulin, S., Labonté-Chartrand, G., Robillard, G., and Renaud, P. (2006). *Perceived realism has a significant impact on presence.* Paper presented at the 11th Annual CyberTherapy Conference, Gatineau, Quebec, Canada, June.

Factors:	Anxiety manipulation (expect in real room with mouse, expect replica of real room).
Computing platform:	IBM Pentium IV with ATO graphics card.
Visual display:	Visor HMD covered by a 30 × 40 cm black cloth. Two videoconference units with false links to several computers to create the illusion that the VR environment is a live feed from the videoconference system.
Tracking:	Intertrax tracking.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Simple room with notice board and cage holding a mouse.
Training:	Immersion in a neutral/irrelevant virtual world to learn how to navigate and the concept of presence. Followed by short measure of presence.
Experimental task:	Depending on condition, either watch a video showing a mouse in a cage or discuss in teleconference with an assistant who is showing a mouse in a cage. Then participants were falsely led to believe they would be immersed in an RE, in real time, with a real mouse in a cage. In the control condition, participants were told the immersion would take place in a virtual world that was a replica of a real room.
Participants:	37 participants; 78.4% female; age range 18 to 62; mean age 33.1 years. 11 participants were diagnosed as suffering from rodent phobia (rats/mice).
Study design:	Between-subjects.
Presence measures:	Witmer-Singer PQ, rating.
Person-related meas.:	Witmer-Singer ITQ.
Task-related measures:	Kennedy SSQ.
Findings: (1)	Anxiety manipulation had no significant relationship with ratings taken after initial immersion and after experimental immersion. There was a significant interaction, such that participants in the experimental condition gave higher ratings for the second immersion than for the first, while participants in the control condition gave lower ratings for the second immersion.

[Bouchard 2004] Bouchard, S., St.-Jacques, J., and Renaud, P. (March 2004). Anxiety Increases the feeling of presence in virtual reality. *Presence-Connect, 4*.

Factors:	Type of virtual world (neutral/control environment, desert-like environment without induced anxiety).
Computing platform:	PC with ATI Technologies, Inc. Radeon graphic card.
Visual display:	i-O Display Systems I-Glass HMD, with 640 × 480 resolution, 26º diagonal FOV.
Tracking:	Head tracking using an InterSense InterTrax 3 DOF tracker.
Navigation:	Microsoft joystick.
Object manipulation:	None.
Virtual world:	The neutral/control virtual world was based on a modified version of the Assault-Mazon map of the 3D game Unreal Tournament – Game of the Year Edition®. The desert-like environment mirrored snakes' natural habitat and was based on a modified version of the map "The Temple of Horus" from the game Unreal Tournament – Game of the Year Edition®.
Training:	During exploration of the neutral/control world.
Experimental task:	Explore the neutral/control virtual world. Then explore the second virtual world, once when told no snakes were present and once when told that poisonous, aggressive, and dangerous snakes were hidden and lurking in it. Participants

		performed a reading-based distraction task between the last two sessions. 5-min exposure to each virtual world.
Participants:		31 participants; 5 males; age range 27 to 68. Suffered from a specific phobia of snakes but did not suffer from major depression, psychotic disorders, or any other mental disorder that would require immediate treatment and were not taking drugs or substances that would block the effect of anxiety. Had no prior experience with VE systems.
Study design:		Within-subjects.
Presence measures:		PQ, verbal rating of presence halfway through and at end of each session.
Person-related meas.:		State-Trait Anxiety Inventory.
Task-related measures:		*Kennedy SSQ*.
Performance-related measures:		Verbal rating of anxiety halfway through and at end of each session.
Findings:	(1)	Anxiety-inducing-world participants reported significantly higher verbal ratings and significantly higher PQ scores.
	(2)	Verbal rating of presence had a significant correlation with PQ Total scores at the mid-point and end of the session in the controlled environment.
	(3)	Anxiety had a significant positive correlation with the midpoint and final rating of presence for the last two sessions. The correlations between change scores in anxiety and presence from the second to the third immersion also were significant for the mid-point and final presence ratings.
	(4)	*Anxiety-inducing-world participants reported significantly more anxiety.*
	(5)	*Type of virtual world had no significant relationship with SSQ scores.*

[Bracken 2005 (1)] Bracken, C. C., and Skalski, P. (2005). Presence and video games: The impact of image quality and skill level. *Proceedings of the 55th Annual Conference of the International Communication Association*, New York, USA, May.

Factors:		Image quality (enhanced definition, NTSC (National Television System(s) Committee)), skill level (high, low).
Computing platform:		Microsoft Xbox 360.
Visual display:		Rear projection television (TV) with 65-in. screen.
Auditory display:		Using TV.
Tracking:		No.
Navigation:		Xbox console system.
Object manipulation:		Xbox console system.
Virtual world:		Halo First Person Shooter (FPS) video game.
Training:		Brief instruction from experimenter, followed by short practice session where experiment guided participant to a set point in the game. 3 to 10 min.
Experimental task:		Continue on with game. 10 min.
Participants:		22 students; 11 males; age range 14 to 53; mean age 24.1 years.
Study design:		Between-subjects.
Presence measures:		Questionnaire adapted from Lombard and Ditton's questionnaire, with 9 items addressing involvement and immersion, 3 items addressing spatial presence.
Person-related meas.:		9-item skill level questionnaire.
Findings:	(1)	Image quality had no significant relationship with spatial presence or immersion scores.
	(2)	Skill level had no significant relationship with spatial presence scores. There was an interaction with skill level, such that participants with higher skill levels reported significantly more spatial presence when using the high image quality.
	(3)	Participants with lower gaming skill levels reported significantly more immersion.

[Bracken 2005 (2)] Bracken, C. C., and Skalski, P. (2005). Presence and video games: The impact of image quality and skill level. *Proceedings of the 55th Annual Conference of the International Communication Association*, New York, USA, May.

Factors:	Image quality [high definition (HD), NTSC)], skill level (high, low).
Computing platform:	Microsoft Xbox 360.
Visual display:	Rear projection TV with 65-in. screen.
Auditory display:	Using TV.
Tracking:	No.
Navigation:	Xbox console system.
Object manipulation:	Xbox console system.
Virtual world:	Perfect Dark Zero FPS video game.
Training:	Brief instruction from experimenter, followed by short practice session where experiment guided participant to a set point in the game. 3 to 10 min.
Experimental task:	Continue on with game. 10 min.
Participants:	50 students; 25 males; age range 18 to 29; mean age 23.02.
Study design:	Between-subjects.
Presence measures:	Questionnaire adapted from Lombard and Ditton's questionnaire, with 9 items addressing involvement and immersion, 3 items addressing spatial presence.
Person-related meas.:	9-item skill level questionnaire.
Findings: (1)	Image quality had no significant relationship with spatial presence or immersion scores.
(2)	Participants using HD reported significantly higher levels of immersion.
(3)	Skill level had no significant relationship with spatial presence scores.
(4)	Participants who had lower gaming skill levels reported significantly more immersion.

[Brogni 2003] Brogni, A., Slater, M., and Steed, A. (2003). *More breaks less presence*. Paper presented at the 6th International Workshop on Presence, Aalborg, Denmark, October.

Visual display:	Trimension Reactor with 4 walls.
Tracking:	Using InterSense system.
Navigation:	Using a wand.
Object manipulation:	None.
Virtual world:	Urban environment.
Training:	Training in recognition of breaks in presence (BIPs) through visualization of Gestalt 2D images.
Experimental task:	Experience urban environment, pressing a button on the wand to indicate a BIP. 4–5 min.
Presence measures:	Count of BIPs, 4-item SUS questionnaire.
Task-related measures:	4-item consistency check questionnaire.
Findings: (1)	Count of BIPS had a significant negative correlation with reported presence.
(2)	Three of four items on the consistency check questionnaire had a significant correlation with reported presence in the expected direction.

[Brown 2003] Brown, S., Ladeira, I., Winterbottom, C., and Blake, E. (2003). An investigation on the effects of mediation in a storytelling virtual environment. *Proceedings of the 2nd International Conference on Virtual Storytelling*, Toulouse, France, November, 102–111.

Factors:	Content form (visual and audio, visual, audio, none).
Computing platform:	Two PCs. Genesis3D engine.
Visual display:	19-in. monitors, frame rate 10 to 20 fps.
Audio display:	Headphones.

Tracking:	None.
Navigation:	Mouse (for pitch and yaw), keyboard (for movement, sitting, and standing).
Object manipulation:	None.
Virtual world:	Cave at night time, where cave is situated on rough, barren terrain with digital photographs of the Cederberg mountains used to texture rocks. Interior of cave includes a fire surrounded by 3 figures. Sound partially spatialized to provide direction and location. Visual mediation consisted of San rock paintings; audio mediation was sounds of fire cracklings and crickets chirping.
Experimental task:	Approach the group around the fire. Listen to welcome from storyteller and then sit and listen to story with other San hunters.
Training:	Practice in virtual Familiarity Room.
Participants:	77 first- and second-year Economics and Psychology students.
Study design:	Between-subjects.
Presence measures:	Igroup Presence Questionnaire (IPQ).
Task-related measures:	Rating of involvement in story, rating of enjoyment in virtual world.
Findings: (1)	Visual mediation had no significant relationship with presence.
(2)	Use of audio mediation was associated with significantly higher presence scores.
(3)	Enjoyment and involvement had a significant positive correlation with presence.
(4)	*Enjoyment and mediation had a significant interaction, with visual mediation effecting enjoyment only when audio mediation was present and vice versa.*
(5)	*Visual mediation had a significant relationship with involvement.*

[Bystrom 1999] Bystrom, K.-E., and Barfield, W. (1999). Collaborative task performance for learning using a virtual environment. *Presence, 8* (4), 435–448.

Factors:	Collaboration (single user, pair), navigation (control of movement and navigation, control of movement only, control of navigation only, no control), head tracking (present, absent).
Computing platform:	SGI Indigo Extreme workstation. In-house software.
Visual display:	GE 610 6 × 8 ft rear projection screen. Images displayed using StereoGraphics Corporation CrystalEyes shutter glasses with 1280 × 512 pixel resolution. Update rate 6 fps. Participants seated in front of projection screen so that their position subtended a 90º FOV with the display screen.
Tracking:	Polhemus 3Space FASTRAK for head tracking.
Navigation:	Standard mouse controlled by participant with head tracking, located on small table in front of participant. The participant who “controlled” navigation operated mouse or gave instructions to mouse controller.
Object manipulation:	None.
Virtual world:	Virtual room with objects such as tables, chairs, a desk, a bookshelf, a telephone, and a notepad. 6 versions of the room formed by relocating certain objects.
Experimental task:	Navigate through a virtual room and identify objects moved from position given on a provided diagram. Took diagram of room showing initial object locations into VE, along with additional diagram onto which marked changes of location. 2 treatments alone, 4 working with a partner. Each trial 3 min.
Participants:	20 participants recruited from university engineering classes, and software companies or associations; 10 males; age range 16 to 49; mean age 28 years. 9 participants had previous VE experience; 4 of these had over 20 min. 8 pairs of participants knew each other prior to the study.
Study design:	Within-subjects.
Presence measures:	11-item presence questionnaire, 6 items answered by all participants, remaining questions depending on condition.
Performance measure:	*Number objects correctly identified, with movement also correctly identified*.
Findings: (1)	Collaboration had no significant main effect on presence, but those who worked with a known partner reported significantly more presence than those who worked with a stranger.

(2) Navigation had no significant relationship with presence.
(3) Use of head tracking was associated with significantly higher presence score for only 1 question ("How realistically did the virtual world move in response to your head motions?")
(4) Collaboration between a pair was associated with improved task performance.
(5) Navigation had a significant relationship with task performance, with better performance for those working alone who had more control or those working with a partner than for those working alone with no control.
(6) Head tracking had no main effect on task performance. There was a significant interaction with collaboration, such that use of head tracking was associated with significantly better performance when both participants had head tracking.

[Bystrom 1996] Bystrom, K.-E., and Barfield, W. (1996). Effects of participant movement affordance on presence and performance in virtual environments. *Virtual Reality, 2* (2), 206–216.

Factors: Movement (seated with chin rest, seated without chin rest, standing).
Computing platform: SGI Indigo Extreme workstation. In-house software.
Visual display: GE 610 6 × 8 ft rear projection screen. Images displayed using StereoGraphics Corporation CrystalEyes shutter glasses with 1280 × 512 pixel resolution. Update rate 9 fps. Participants positioned initially so their position subtended a 90° FOV with the projection screen.
Tracking: Polhemus 3Space FASTRAK for head tracking.
Navigation: Standard mouse attached to a clipboard—either hand-held or, for chin-rest condition, placed on table in front of participant.
Object manipulation: None.
Virtual world: Virtual cabin with furniture including tables, chairs, a desk, a bookcase, windows with outside scenes, and cupboards. 7 target (A–M) letters positioned around room, mixed with 6 distracter (N–Z) letters. Different versions of room prepared by moving letters. 3 versions for practice trials; 3 versions for experimental trials.
Experimental task: Locate the target letters. No time limit. Focus on accuracy rather than speed.
Participants: 11 participants from university engineering classes and local software community; 7 males; age range 21 to 9; mean age 25 years. 6 participants had previous VE experience, 5 of these had more than 20 min of experience.
Study design: Within-subjects.
Presence measures: 11-item questionnaire including overall presence rating.
Person-related meas.: Age.
Task-related measures: Rating of task difficulty, rating of enjoyment.
Performance measure: Search time.
Findings:
(1) Movement had no significant relationship with the rating of presence.
(2) Presence had a significant relationship with search time only for participants who reported that their sense of presence increased when seated.
(3) Presence had no significant correlation with age, a significant positive correlation with response realism and realism of depth/volume, and a significant negative correlation with reports that presence was affected by standing.
(4) Movement had no significant relationship with ratings of realism of depth/volume, ability to reach into VE, task difficulty, or enjoyment. There was a significant effect for head movement realism, with more realism reported by participants who stood or sat.
(5) Movement had no relationship with task performance. There was a significant interaction between task complexity and gender, such that males performed better in the more complex task, whereas females faired better in the simple task.
(6) Task performance had a significant positive correlation with task difficulty and reports that presence was affected by sitting but had no significant correlation with age, response realism, depth/volume realism, ability to reach into VE, or enjoyment.

[Casanueva 2001 (1)] Casanueva, J. (April 2001). *Presence and co-presence in collaborative virtual environments*. Master's thesis, University of Cape Town, South Africa.

Factors:		Collaboration (group members had to collaborate to unlock padlocks attached to shapes, no collaboration required).
Computing platform:		SGI Onyx RealityEngine2 with four 200-MHz R4400, 128 MB RAM. SGI O2 with a 175-MHz MIPS R10000 processor, 128 MB RAM. SGI O2 with a 195-MHz MIPS R10000 processor, 256 MB RAM. DIVE software developed by the Swedish Institute of Computer Science, supporting avatar gravity and collision detection, and University College London Robust Audio Tool (RAT) audio software.
Visual display:		Two 21-in. monitors, one 17-in. monitor.
Audio display:		Headphones.
Navigation:		Using keyboard arrow keys.
Object manipulation:		Pick up and move objects by clicking and releasing mouse button.
Virtual world:		Set of rooms with textured walls, floors, and ceiling that formed a virtual maze. Participants represented by simple "T-shaped" avatars, each participant with a different color (Red, Blue, Green). Participants could not see their own avatar. Audio communications between participants in a group using microphones and headphones.
Training:		Familiarization with VE, including learning how to move through the environment, and pick up objects.
Experimental task:		Move pyramids, cubes, and rectangles into the room marked for each type of shape. Shapes colored to match avatars and could be picked up only by an avatar of the same color. In high-collaboration condition, each shape has an attached padlock of different color, requiring 2 members to collaborate with one clicking to unlock padlock and another to pick up shape within 6 sec. No padlocks were used in the low-collaboration condition. 25-min time limit.
Participants:		10 groups of 3 students from 2nd year psychology course.
Study design:		Between-groups.
Presence measures:		5-item SUS questionnaire, co-presence questionnaire.
Person-related meas.:		19-item Witmer-Singer ITQ.
Task-related measures:		14-item collaboration and group accord questionnaire.
Findings:	(1)	Required collaboration was associated with significantly higher presence, co-presence, and collaboration score.
	(2)	Co-presence had no significant correlation with presence.
	(3)	Collaboration score had a significant correlation with co-presence, positive in the high-collaboration condition and negative correlation in the low-collaboration condition. Collaboration score had no significant correlation with presence.
	(4)	ITQ score had a significant positive correlation with presence, but a significant positive correlation with co-presence only when group collaboration was required for task performance.
	(5)	*Collaboration had a significant positive association with collaboration score.*

[Casanueva 2001 (2)] Casanueva, J. (April 2001). *Presence and co-presence in collaborative virtual environments*. Master's thesis, University of Cape Town, South Africa.

Factors:	Presence manipulation (high presence, low presence).
Computing platform:	SGI Onyx ReaityEngine2 with 128 MB RAM. SGI O2 with a MIPS R10000 processor, 256 MB RAM. SGI O2 with a MIPS R10000 processor, 128 MB RAM. DIVE and RAT software. SGI Indy for recording dialogue in high-presence environment.
Visual display:	Two 21-in. monitors, one 17-in. monitor.
Audio display:	Headphones (and microphones) in high presence condition.

Navigation:		Using keyboard arrow keys.
Object manipulation:		Pick up and move objects by clicking and releasing button on 3-button SGI mouse.
Virtual world:		10 rooms in an open plan office layout, each with a word printed on either the wall (high-presence) or floor (low-presence). Each word with missing letters. These letters scattered in the form of 10 cubes that had the letter written on all sides. Self-representation as colored avatars.
Training:		Practice session in the VE, where participants learned how to move through the environment, communicate with each other, and how to pick-up and drop objects.
Experimental task:		Pick up and move cubes to place correct missing letter by each word. Letters could be used in more than 1 word. In low-presence condition, experimenter interrupted participant by asking about and then bringing a soft drink. 25-min time limit.
Participants:		6 groups of 3 students and 1 group of 2 students; 9 males.
Study design:		Between-groups.
Presence measures:		34-item Witmer-Singer PQ, co-presence questionnaire, total presence (weighted sum of presence and co-presence scores).
Person-related meas.:		19-item Witmer-Singer ITQ.
Findings:	(1)	High-presence participants reported significantly more co-presence and total presence but not significantly different presence.
	(2)	Co-presence had no significant correlation with presence.
	(3)	Co-presence and total presence scores had no significant correlation with ITQ scores. Presence had a significant positive correlation with ITQ scores in the high presence environment only.
	(4)	Presence manipulation had no significant relationship with ITQ scores.

[Casanueva 2001 (3)] Casanueva, J. (April 2001). *Presence and co-presence in collaborative virtual environments*. Master's thesis, University of Cape Town, South Africa. See also Casanueva, J. S., and Blake, E. H. (2000). *The effects of avatars on co-presence in a collaborative virtual environment* (Report CS01-02-00). South Africa: University of Cape Town, Collaborative Computing Laboratory, Department of Computer Science.

Factors:		Avatar realism (realistic human-like, cartoon-like, unrealistic).
Computing platform:		SGI Onyx RealityEngine2 with four 200-MHz MIPS R4400 processors, 128 MB RAM. SGI O2 with a 175-MHz MIPS R10000 processor, 128 MB RAM. SGI O2 with 195-MHz MIPS R10000 processor, 256 MB RAM, DIVE and RAT software.
Visual display:		Two 21-in. monitors, one 17-in. monitor.
Audio display:		Headphones (and microphones).
Navigation:		Using keyboard arrow keys.
Object manipulation:		Pick up and move objects by clicking and releasing mouse button.
Virtual world:		Conference room where multiple users meet around a table and have a discussion. Each participant had a book on the table that could be used to view a document. Whiteboard on one wall. Fully textured. Participants could not see their own avatar. Avatars of others had no gestures or facial expressions.
Training:		Learning how to move through the environment and pick up objects.
Experimental task:		Read a short story by accessing the book on the virtual table and agree on a ranking for the 5 characters in the story, using a grid display and markers on the whiteboard to aid the discussion. 20-min time limit.
Participants:		6 groups of 3 students from 2nd year psychology course.
Study design:		Between-groups.
Presence measures:		5-item SUS questionnaire, co-presence questionnaire.
Person-related meas.:		19-item Witmer-Singer ITQ.
Findings:	(1)	Participants seeing realistic avatars reported significantly more co-presence.
	(2)	Co-presence had no significant correlation with presence.
	(3)	ITQ score had a significant positive correlation with presence but no significant relationship with co-presence.

[Casanueva 2001 (4)] Casanueva, J. (April 2001). *Presence and co-presence in collaborative virtual environments*. Master's thesis, University of Cape Town, South Africa. See also Casanueva, J. S., and Blake, E. H. (2000). *The effects of avatars on co-presence in a collaborative virtual environment* (Report CS01-02-00). South Africa: University of Cape Town, Collaborative Computing Laboratory, Department of Computer Science.

Factors:		Avatar functionality (gestures, gestures and facial expressions, no functionality).
Computing platform…		
Experimental task:		As in [Casanueva 2001 (3)], except avatars had gestures (waving, raising arms, joy and sad gestures, head movements such as yes, no, and perhaps, and walking) and facial expressions (sad, happy, neutral, surprised, disgusted, angry, furious).
Participants:		10 groups of 3 students from 2nd year psychology course.
Study design:		Between-groups.
Presence measures:		5-item SUS questionnaire, co-presence questionnaire.
Person-related meas.:		19-item Witmer-Singer ITQ.
Findings:	(1)	Participants seeing avatars with gestures and facial expression reported significantly more co-presence.
	(2)	Co-presence had no significant correlation with presence.
	(3)	ITQ score had a significant positive correlation with presence but had no significant relationship with co-presence.

[Chapman 2003] Chapman, K., Freeman, J., Keogh, E., Dillon, C., Jorquera, M., Rey, B., Baños, R., and Raya, M. A. (2003). *Investigating the relationship between presence and emotion using virtual mood induction procedures.* Paper presented at the 6th International Workshop on Presence, Aalborg, Denmark, October.

Visual display:		Projection screen 127 × 94 cm, viewing distance to provide 24º H × 18º V FOV.
Tracking:		None.
Navigation:		None.
Object manipulation:		None.
Virtual world:		Different versions of a park containing a pagoda, statue, water pool, cinema and trees. Variations include time of day, and weather associations with mood.
Experimental task:		View a fly through of one version of a sad, happy, anxious, relaxed, or neutral version of the park.
Participants:		127 students.
Study design:		Within-subject.
Presence measures:		ITC-SOPI, *SUS Questionnaire*.
Person-related meas.:		Visual Analogue Scale (VAS), Positive and Negative Affect Schedule (PANAS).
Findings:	(1)	VAS scores had a significant correlation with ITC-SOPI scores, only examined for the sad and anxious versions of the park.
	(2)	PANAS scores had a significant correlation with ITC-SOPI scores, only examined for the sad and anxious versions of the park.
	(3)	*Viewing the park had a significant relationship with VAS and PANAS scores for the sad and anxious versions of the park.*

[Chartrand 2005] Chartrand, G. L.-, and Bouchard., S. (92005). *Emotions may not have to match with the content afforded by the virtual environment to induce presence.* Paper presented at the 11th Annual CyberTherapy Conference, Gatineau, Quebec, Canada, June.

Factors:	Content (mood induction, neutral).
Computing platform:	IBM Pentium IV with an ATI Technologies, Inc. 128-MB graphics card.
Visual display:	I-Visor HMD.
Tracking:	InterSense head tracking.

Virtual world:		Experimental virtual world was the Temple of Horus taken from *Unreal Tournament: Game of the Year*.
Experimental task:		Neutral immersion followed by Velten procedures for induction of positive or negative emotions and immersion in Horus.
Participants:		28 participants; 10 males; age range 19 to 52; mean age 28.54 years. Inclusion criteria: no previous experience of virtual reality, not wanting to visit Egypt, at least 18 years of age.
Presence measures:		Witmer-Singer PQ, rating.
Findings:	(1)	Content had no significant relationship with PQ scores or presence rating.

[Cheung 2002] Cheung, P., and Marsden, P. 2002. Designing auditory spaces to support sense of place: The role of expectation. *CSCW 2002 Workshop: The Role of Place in Shaping Virtual Community*, New Orleans, USA, November.

Factors:		Stimuli (matching, mismatching),
Computing platform:		Pentium PC. Replay using Macromedia Director. Physiological data collection using Datalab 2000 with Biobench software.
Visual display:		Projection screen, resolution 800 × 600.
Audio display:		Binaural sound recordings played over Sennheiser H2270 headphones.
Tracking:		None.
Audio sequences:		Sounds clips of 60-sec length recorded from a pub, supermarket, higher street, and train station.
Visual stills:		Matching audio sequences.
Training:		Listen to recording and view image of a park.
Experimental task:		Listen to audio while viewing still image. 4 trials. Approximately 20 min.
Participants:		20 students and university staff.
Study design:		Between-subjects.
Presence measures:		9-item version of Swedish Viewer-User Presence (SVUP).
Task-related measures:		*Δskin conductance, Δblood pressure*.
Performance measures:		*Memory test of place-related questions*.
Findings:	(1)	Participants with matching audio-visual stimuli reported significantly more presence.
	(2)	*Stimuli had no significant relationship with task performance.*
	(3)	*Stimuli had no significant relationship with skin conductance or blood pressure*.

[Cho 2003] Cho, D., Park, J., Kim, G. J., Hong, S., Han, S., and Lee, S. (2003). The dichotomy of presence elements: The where and how. *Proceedings of IEEE Virtual Reality 2003,* Los Angeles, USA, March, 271–272. See also Lee, S., Kim, G. J., Sukhatme, G. S., and Park, C.-M. (2004). Effects of haptic feedback on telepresence and navigational performance. *Proceedings of the 14th International Conference on Artificial Reality and Telexistance,* Seoul, Korea, November–December.

Factors:	Stereoscopy (present, absent), user motion (fixed navigation, none), object motion (moving fish, stationary fish), object self-motion (with deformation, no deformation), geometry (high polygon count, low polygon count), texture (present, absent).
Visual display:	50-in. screen.
Audio display:	None.
Tracking:	None.
Navigation:	Either fixed or none.
Object manipulation:	None.
Virtual world:	Simple undersea world with rocks and fish.
Experimental task:	View 32 versions of virtual world for 90 sec each.
Presence measures:	4-item realism and presence questionnaire.
Task-related measures:	*Ranking of importance of 5 visual elements for creating a sense of being in the undersea world.*

Findings: (1) Stereoscopy, geometry, and texture had a significant relationship with presence.
(2) User motion had a significant relationship with presence and a significant interaction with texture.
(3) Object motion had a significant relationship with presence and a significant interaction with geometry and texture.
(4) Object self-motion had no significant relationship with presence.
(5) Stereoscopy, object motion, and user motion had a significant relationship with realism.
(6) Geometry had a significant relationship with realism and a significant interaction with object motion.
(7) Texture had a significant relationship with realism and a significant interaction with object motion and user motion.
(8) Object self-motion had no significant relationship with realism.

[Choi 2001] Choi, Y. K., Miracle, G. E., and Biocca, F. (2001). The effects of anthropomorphic agents on advertising effectiveness and the mediating role of presence. *Journal of Interactive Advertising, 2* (1).

Factors: Avatar use (advertising avatar, no avatar).
Computing platform: Developed using 3D Studio Max, Character Studio, and Macromedia Director 7.
Visual display: Desktop monitor.
Web site: Designed to market t-shirts and socks under a fictitious brand name. Included a welcome message for customers, information search options, purchase instructions, and farewell message in a 3D background setting. The version with an agent presented messages using the agent voices and nonverbal cues such as head nodding, waving hands, and moving arms. The same message was provided in textual format in the other version.
Experimental task: Navigate to Web site and then examine site.
Participants: 207 undergraduate students from introductory advertising classes.
Study design: Between-subjects.
Presence measures: 10-item presence questionnaire, 6-item social presence questionnaire.
Task-related measures: *Attitude toward the advertisement, attitude toward brand, intention to purchase, intention to revisit Web site scales (used as measures of advertising effectiveness).*
Findings: (1) Participants who saw an avatar reported significantly more presence.
(2) Presence had a significant positive correlation with social presence and social presence.
(3) Presence and social presence had a significant positive correlation with intention to revisit the Web site, and various mediating relationships with advertising effectiveness were found.
(4) Participants who saw an avatar reported significantly more positive attitudes toward the advertisement and intention to revisit the Web site. Avatar use had no significant relationship with attitude toward brand or intention to purchase.

[Commarford 2001] Commarford, P. M., Singer, M. J., and King, J. P. (2001). Presence in distributed virtual environments. *Proceedings of the 9th International Conference on Human-Computer Interaction,* New Orleans, USA, August, 644–648.

Computing platform: SGI Onyx and RealityEngine2 with eight 200-MHz MIPS R4400 processors, 256 MB RAM. In-house software.
Visual display: Stereoscopic, color Virtual Reality VR8 HMDs.
Audio display: Stereo headphones.
Tracking: Head, each ankle, right wrist and elbow, and harness sensors tracked by an Ascension Technology's MotionStar (wired version) with an extended range transmitter.
Navigation: Walking-in-place on a platform with barrier.

Virtual world:	Several scenarios using 10-room virtual buildings laid out along a single corridor approximately 4 m wide with one 90º turn, either to the right or left. Corridors all scaled to 70 m in length, with the turn at 20, 25, or 30 m. Rooms varied between 5 × 10 m and 15 × 10 m in size, with office furniture, home furnishings, warehouse shelving, bookcases, and desks placed in realistic arrangements. The buildings were designed to represent normal offices, a school, a department store, a library, a warehouse, and single-story homes. The scenarios ranged from simple to complex, with varying numbers of neutral hostages, opposing forces, and gas canisters. Canisters had 1 or 3 possible states: no gas and not armed, gas and not armed, and gas and armed. Sound cues included voice communications, collision noises, door opening, grenade explosions, and gunfire.
Training:	Worked as individuals and in teams with an automated partner for 4-hr training session on VE equipment and tasks, in which exposed to VE 3 to 4 times. Started with walking through a simple VE; final training included equipment operation and team tasks partnered with an automated agent.
Experimental task:	Paired with partner to complete a series of 8 VE mission rehearsals. Each mission involved searching for and disarming gas canisters.
Participants:	64 students.
Person-related meas.:	29-item ITQ Version 2.0.
Presence measure:	Winter-Singer PQ.
Findings: (1)	PQ scores taken after final training were significantly different from PQ scores after initial, simple movement training for PQ Total, and PQ Natural, Involved/ Control, Auditory, and Haptics subscales, with higher presence reported after final training.
(2)	PQ scores taken after the first team mission were significantly different from PQ scores after final training for PQ Total and PQ Involved/Control subscale, with higher presence reported after final training.
(3)	PQ scores taken after the last team mission were significantly different from PQ scores after the first mission for PQ Total and PQ Involved/Control subscale, with increased presence reported after the final mission.
(4)	When measured after initial training, ITQ Focus subscale had a significant positive correlation with PQ Total and PQ Involved/Control and PQ Resolution subscales.
(5)	When measured after final training, ITQ scores had no significant correlation with PQ scores.

[Darken 1999 (2)] Darken, R. P., Bernatovich, D., Lawson, J. P., and Peterson, B. (1999). Quantitative measures of presence in virtual environments: The roles of attention and spatial comprehension. *CyberPsychology & Behavior, 2* (4), 337–347. See also Bernatovich, D. (1999). *The effect of presence on the ability to acquire spatial knowledge in virtual environments*. Master's thesis, Naval Postgraduate School, Monterey, CA.

Factors:	Audio cues (semantic and spatial information, semantic information, spatial information, no cues).
Visual display:	3-screen semi-circular mini-Cave.
Navigation:	Joystick for viewpoint control only.
Object manipulation:	None.
Virtual world:	Participant given a guided car tour of a town. Semantic audio cues provided information such as "This Mobil Station has a car wash and was built 3 years ago"; spatial audio cues provided information such as "This Mobil Station is on the north side of town adjacent to the park."
Experimental task:	Observe the virtual world while on an automated car tour.
Participants:	40 participants; 33 males; mean age 32.5 years.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 2.0.

Performance measures:		Spatial knowledge acquisition: map building and pointing task scores, number correct landmarks selected.
Findings:	(1)	Participants with semantic and spatial information cues reported significantly higher PQ scores than those who no audio cues.
	(2)	Map building and landmark identification scores had no significant correlation with PQ scores.
	(3)	*Audio cues had no significant relationship with map building scores or pointing task scores but had a significant relationship with landmark selection with both the spatial and spatial-with-semantics cues giving better performance.*

[Dinh 1999] Dinh, H. Q., Walker, N., Song, C., Kobayashi, A., and Hodges, L. F. (1999). Evaluating the Importance of multi-sensory input on memory and the sense of presence in virtual environments. *Proceedings of IEEE Virtual Reality 1999*, Houston, USA, March, 222–228.

Factors:		Tactile cues (present, absent), olfactory cues (present, absent), audio cues (present, absent), visual detail (high detail, low detail).
Computing platform:		Modeled using Alias Wavefront. Rendered by in-house software built using Georgia Institute of Technology's Simple Virtual Environment (SVE) toolkit.
Visual display:		HMD with frame rate 20 fps.
Tactile display:		Tactile cues, when present, were a real fan to produce effect of virtual fan and heat lamp used to simulate standing in sunshine.
Olfactory display:		Olfactory cue was the scent of coffee delivered using a small oxygen mask connected to (1) a canister of coffee grounds and a small pump and (2) fresh air source and additional pump.
Auditory display:		Delivered via headphones: sound of a fan, a toilet flushing, a copier machine, and city noise; volumes (usually on/off) varied according to participant's location.
Tracking:		Head tracking.
Navigation:		None, participant positioned at 2 locations within each room in the VE.
Object manipulation:		None.
Virtual world:		Corporate office suite including a reception area, hallway, bathroom, small office, copier room, larger office, and balcony. All spaces appropriately furnished. Texture mapping for pictures, furniture material, and an outdoor city view. For high visual detail, local light sources were simulated and high-resolution text maps used; for low visual detail, used only ambient lighting and reduced texture resolutions to 25% previous value.
Training:		Training room containing objects, such as books on the floor, a table, a vase, and a speaker. Training task to find each of 5 specific objects.
Experimental task:		Evaluate the effectiveness of a VE system for use by real estate brokers. Virtual tour took approximately 5 min.
Participants:		322 undergraduate students. At most, 1 had previous experience in a VE.
Study design:		Between-subjects.
Presence measures:		14-item questionnaire, including an overall rating of presence.
Performance measures:		*Memory test with 4 items on spatial layout questionnaire, 5 items on object location.*
Findings:	(1)	The use of audio cues and tactile cues were associated with significantly higher presence scores.
	(2)	Visual detail and olfactory cues had no significant relationship with presence.
	(3)	*Audio, tactile, visual, and olfactory cues had no significant relationship with spatial layout memory. Tactile and olfactory cues had a significant relationship with object location memory; audio and visual cues had no significant effect.*

[Dumoulin 2006] Dumoulin, S., Robillard, G., Villemaire, C., and Bouchard, S. (2006). *Impact of the sense of presence on distraction in virtual reality*. Paper presented at the 11th Annual CyberTherapy Conference, Gatineau, Quebec, Canada, June.

Factors:	Visual display (3-sided Cave, high-end HMD, low-end HMD).
Visual display:	3-sided 10 × 10 × 10 ft wall Cave viewed with NuVision 3D glasses; nVisor SX HMD 1280 × 1024 resolution, 60º FOV; I-Glass 800 × 600 resolution, 26º FOV.
Tracking:	Motion tracking for Cave, nVisor SX using IS-900; head tracking with I-Glasses using InterSense I-Cube.
Navigation:	Via motion tracking and wand for Cave and nVisor SX wireless mouse for I-Glasses.
Object manipulation:	None.
Virtual world:	Virtual apartment with furnishings. After the first minute, an electric sander (distraction) was heard continuously at 90 db for the rest of the session.
Training:	Prior to immersion, a narrative context was provided for the experimental task.
Experimental task:	Visit a virtual apartment and gather information about colors of different objects.
Participants:	27 participants, age 20 to 57 years.
Study design:	Within-subjects.
Presence measures:	Questionnaire.
Task-related measures:	*Distraction measure*, *system rating*.
Findings: (1)	After the first minute, participants gave significantly higher presence scores for the Cave than for the high-end HMD and significantly higher presence for the high-end HMD than for the low-end HMD.
(2)	Distracter did not significantly reduce presence scores.
(3)	*Participants' ratings for which system was most powerful in distracting them from the noise were significantly higher for the high-end HMD.*
(4)	*Type of visual display had no significantly relationship with distracter scores.*

[Durlach 2005] Durlach, P. J., Fowlkes, J., and Metevier, C. J. (2005). Effects of variations in sensory feedback on performance in a virtual reaching task. *Presence, 14* (4), 450–462.

Factors:	Hand fidelity (detail hand model, angular and black), constraint (no object penetration, could penetrate objects), feedback modality (auditory, tactile).
Computing platform:	Pentium III 1-GHz computer with timing resolution 10 ms.
Visual display:	Virtual Research V6 HMD with 742 × 230 resolution, 48º × 36º FOV. Participant seated with chin-rest.
Auditory display:	Headphones for sound generated by 16-bit monaural WAV file at 22.05 kHz.
Haptic display:	Virtual Technology CyberTouch glove worn on right hand to provide vibration to middle finger.
Tracking:	CyberGlove for tracking hand and finger movement.
Navigation:	None.
Object manipulation:	Using CyberGlove to touch start button and targets.
Virtual world:	Yellow targets presented on a grey background, arranged in an outer and semicircle. Red start button.
Training:	Practice trials until participant comfortable and understood task.
Experimental task:	Each trial began with touching start button. After start button turned green, targets would appear on the screen. Participant had to touch each target as quickly and accurately as possible. 40 trials per condition.
Participants:	22 undergraduates; 8 males. All right handed. Those with SSQ scores above 20 at any time were required to drop out (9 of original 31).
Study design:	Within-subjects.
Presence measures:	7-items from Witmer-Singer PQ Involved/Control subscale, 5-item touch scale, both completed after each condition.

Task-related measures: *Simulator Sickness Questionnaire (SSQ)*.
Performance measures: Reaction time, movement time, accuracy (X, Y, Z).
Findings:
(1) Participants gave significantly higher presence scores for the higher fidelity hand.
(2) Participants gave significantly higher presence scores and touch scores for tactile feedback.
(3) Constraint had no significant relationship with presence scores.
(4) Two presence scores and SSQ scores had no significant correlation with any performance measure.
(5) Touch scores had a significant positive correlation for 6 (of 8) conditions.
(6) High-hand fidelity, interpenetration constraint, and tactile feedback modality were related to significantly lower SSQ scores.
(7) Hand fidelity and target position had interaction, such that when the target was collinear with the start button, Reaction time was longer for the high-fidelity hand than for the low-fidelity hand.
(8) Movement time was significantly shorter with a high-fidelity hand (also interaction with target position).
(9) Accuracy had a significant relationship with constraint, target angle, and target distance. Overall, participants were more accurate for interpenetration (versus no penetration) and for targets presented to the left of start button (versus right of start button).

[Eastin 2006] Eastin, M. S., and Griffiths, R. P. (2006). Beyond the shooter game: Examining presence and hostile outcomes among male game players. *Communication Research, 33* (6), 448–466.

Factors: Game interface (VR, standard game console), game content (fighting, shooting, driving), perceived game context (human opponent, computer opponent).
Computing platform: PC.
Visual display: HMD.
Auditory display: Headphones.
Tracking: Motion sensor on HMD for *Knockout Kings 2002*; also wrist sensors and gaming mat.
Navigation: UT: via tracking and joystick-gun; GT3: steering wheel and pedals.
Object manipulation: For *Unreal Tournament: Game of the Year Edition*: joystick made to resemble a gun.
Virtual world: FPS game was *Unreal Tournament: Game of the Year Edition (UT)*. First-person fighting game was *Knockout Kings (KK) 2002*. Control competitive driving game was *Gran Tourismo 3: A-Spec* (GT3). (Whether or not participants were told they were playing against another person, all participants played against the computer).
Training: Allowed to train on assigned game until they felt comfortable with the controls, rarely > 20 min.
Experimental task: Play game for two 10-min sessions.
Participants: 219 males recruited from introductory communication classes, midwestern university; age range 18 to 31; mean age 21.38 years; 95% had previously played a video game, average 70 min/day.
Study design: Between-subjects.
Presence measures: 32-item Witmer-Singer PQ.
Task-related measures: *Hostile expectation bias*.
Findings:
(1) Participants who used the standard gaming console reported significantly higher presence scores.
(2) Participants who played the FPS game gave significantly higher presence scores compared to scores given for the fighting and driving games.
(3) Game context was not associated with any significant differences in presence scores.

(4) *Participants who used the VR system gave significantly higher scores for composite hostile expectation, though not for aggressive behavior, aggressive thoughts, and aggressive feelings when analyzed separately.*

(5) *Participants who played the fighting game gave significantly higher hostile expectations than were given for the FPS and driving games. There was a significant interaction with game interface, such that there were no significant differences among hostile expectations for the gaming console but were relatively high and significantly different in the VR environment.*

(6) *Game context was not associated with any significant differences in hostile expectations.*

[Freeman 2005] Freeman, J., Lessiter, J., Pugh, K., and Keogh, E. (2005). When presence and emotion are related, and when they are not. *Proceedings of the 8th International Workshop on Presence*, London, UK, September, 213–219.

Factors:	Screen size and navigation control (small screen and passive navigation, small screen and self-navigation, large screen and self-navigation).
Computing platform:	Update rate from 22.2 to 30 fps, 60-Hz refresh rate.
Visual display:	Projection screen, large size 129 × 96 cm (37.5º × 28.5º visual angle), small size 38 × 29.5 cm (11.0º × 8.5º visual angle). GFOV manipulation.
Tracking:	None.
Navigation:	Wireless keyboard.
Object manipulation:	None.
Virtual world:	Island with several zones (waterfall, beach 1, beach 2, cloud), each developed to facilitate the delivery of instructions intended to modify negative thinking and anxious mood state. Island supported with imagery that might facilitate relaxation and acceptance, such as calming sea waves and sounds of a tropical island.
Experimental task:	Participants would be asked (or not) to keep their eyes closed. If so, they should try to imagine a scene consistent with any instructions received. Participants in the self-navigation condition were asked to make their way to the beach, which would be signposted in front of them when the environment was displayed. Participants with passive navigation were told to keep their eyes open and navigated (by the experimenter) to the deckchair in the beach zone. On arrival at the beach zone, participant was "seated" in the deck chair located near the shore. At that point, any self-navigation was restricted to left- and right-panning. Then, a prerecorded Acceptance and Commitment Therapy (ACT) narrative was played, lasting 7 min 20 sec.
Participants:	30 participants; 15 males; age range 18 to 34; mean age 25 years. Inclusion criteria: not taking any form of prescription medication (except oral contraceptives), not suffering from any diagnosed emotional/psychological disorder, were not receiving any form of psychological therapy/counseling, had normal or corrected-to-normal vision, had a good grasp of English.
Study design:	Between-subjects.
Presence measures:	44-item ITC-SOPI, *3-item UCL Presence Questionnaire.*
Person-related meas.:	*PANAS emotion scale*, *VAS emotion scale.*

Findings:

(1) Participants with self-navigation gave significantly higher ITC-SOPI Engagement scores and significantly lower Negative Effects scores than participants with passive navigation.

(2) Participants using the large screen gave significantly higher Sense of Physical Space scores (data from self-navigation participants).

(3) *Control of navigation had no significant relationship with VAS or PANAS (pre/post) change scores.*

(4) *Screen size had no significant relationship with VAS or PANAS change scores.*

[Freeman 2004] Freeman, J., Lessiter, J., Keogh, E., Bond, F. W., and Chapman, K. (2004). Relaxation island: Virtual, and really relaxing. *Proceedings of the 7th Annual International Workshop on Presence*, Valencia, Spain, October, 67–72.

Factors:		Virtual world (present, absent).
Visual display:		Projection screen.
Navigation:		Using keyboard.
Object manipulation:		None.
Virtual world:		Island with several zones (waterfall, beach 1, beach 2, cloud), each developed to facilitate the delivery of instructions intended to modify negative thinking and anxious mood state. Island supported with imagery that might facilitate relaxation and acceptance, such as calming sea waves and sounds of a tropical island. When provided, virtual world supported a therapeutic narrative.
Training:		None.
Experimental task:		Listen to therapeutic narrative with eyes close while experimenter navigated to a beach on Relaxation Island or listen to therapeutic narrative and simultaneously navigate self to the beach. Participant seated. Duration 7 min 20 sec.
Participants:		20 students and university staff; 10 males; age range 20 to 56; mean age 30.2 years. Screening based on Acceptance and Action Questionnaire, General Health Questionnaire, Depression Anxiety Stress Scale.
Study design:		Between-groups.
Presence measures:		44-item ITC-SOPI, *3-item UCL Presence Questionnaire*.
Person-related meas.:		PANAS emotion scale and VAS emotion scale.
Findings:	(1)	Use of the virtual world was associated with significantly higher scores for Sense of Physical Space, Engagement, Ecological Validity, and Negative Effects subscales.
	(2)	ITC-SOPI subscales Sense of Physical Space, Engagement, Ecological Validity had a significant positive correlation with changes in VAS happiness.
	(3)	ITC-SOPI Engagement had a significant positive correlation with PANAS Negative Affect changes.
	(4)	*Use of virtual world had a significant relationship with VAS-rated relaxation only.*

[Freeman 2001] Freeman, J., and Lessiter, J. (2001). Here, there, and everywhere: The effects of multi-channel audio on presence. *Proceedings of the 7th International Conference on Auditory Display*, Espoo, Finland, July–August, 231–234. See also Lessiter, J., Freeman, J., Keogh, E., and Davidoff, J. (2001). A cross-media presence questionnaire: The ITC-sense of presence inventory. *Presence, 10* (3), 282–297.

Factors:		Audio type (bass, no bass), number of audio channels (five, two).
Visual display:		28-in. color TV, with participant positioned to provide visual angle 29º.
Audio display:		2 to 5 speakers and a subwoofer positioned behind participant's seat.
Tracking:		None.
Audio sequences:		Sound mixes reflecting a moving car with recordings of engine effects, gear noise, noise of stones hitting base of car as car drove over dips in the road, and noises of bumps while driving over dips.
Visual sequence:		Rally car sequence.
Experimental task:		Listen to audio while viewing video.
Participants:		30 participant; 15 males; age range 18 to 44; mean age 28 years.
Study design:		Within-subjects.
Presence measures:		ITC-SOPI, 3-item SUS Questionnaire.
Task-related measures:		*18-item Media Experience Questionnaire (MEQ).*
Findings:	(1)	Use of bass was associated with significantly higher scores for Sense of Physical Space, Engagement, and Ecological Validity subscales.
	(2)	Number of channels had no significant relationship with ITC-SOPI scores.

(3) Use of bass was associated with significantly higher SUS scores.
(4) Number of channels had no significant relationship with SUS scores.
(5) Use of bass was associated with significantly higher MEQ ratings, with an increased experience for excitement, spaciousness, fullness, clarity, loudness, volume-related discomfort, fidelity, enjoyment, and overall rating. Number of channels had a significant relationship with MEQ items enjoyment, with more enjoyment reported for 5 channels.

[Freeman 2000] Freeman, J., Avons, S. E., Meddis, R., Pearson, D. E., and Ijsselsteijn, W. (2000). Using behavioral realism to estimate presence: A Study of the utility of postural response to motion stimuli. *Presence*, *9* (2), 149–164.

Factors: Stereopsis (present, absent), image motion (present, absent).
Computing platform: Two synchronized Panasonic M2 (A750-B) video players.
Visual display: AEA Technology 20-in. stereoscopic display consisting of 2 BARCO CPM 2053 color monitors with polarized filters, polarized glasses.
Tracking: Ascension Technology's Flock of Birds tracker placed around participant's neck.
Video sequence: Moving video comprised 100 sec. excerpt from rally car sequence filmed for ACTS MIRAGE *Eye to Eye* documentary using camera mounted on car hood; motion capable of evoking lateral postural responses. Still video consisted of frame from *Eye to Eye* footage, where camera situated by side of rally track awaiting rally car to drive by. Synchronized, nondirectional audio track consisting of sounds from car engine, gear changes, and clattering from stones hitting underside of car. Lower sound intensity used for still video.
Experimental task: View video. 4 trials.
Participants: 24 students; 12 males; mean age 25 years; mean height 1.75 m and stereoacuity ≥ 30 sec-arc or better.
Study design: Within-subjects.
Presence measures: Rating of presence on visual-analog scale, lateral postural response.
Task-related measures: *Rating of vection, rating of involvement, rating of sickness*.
Findings:
(1) Use of stereopsis was associated with significantly more presence, but there was no significant difference in postural response.
(2) Moving video was associated with significantly more presence, and significantly more postural response.
(3) Postural response had no significant correlation with presence.
(4) Each of use of stereopsis and moving video were associated with significantly more involvement.
(5) Moving video was associated with significantly more vection. Stereopsis had no significant relationship with vection.
(6) Moving video was associated with significantly more sickness. Stereopsis had no significant relationship with sickness.

[Freeman 1999 (1)] Freeman, J., Avons, S. E., Pearson, D. E., and Ijsselsteijn, W. A. (1999). Effects of sensory information and prior experience on direct subjective ratings of presence. *Presence, 8* (1), 1–13.

Factors: Stereopsis (present, absent), camera motion (observer, scene, minimal).
Computing platform: Two Panasonic M2 (A750-B) video projectors.
Visual display: AEA Technology 20-in. stereoscopic display consisting of 2 BARCO CPM 2053 color monitors, viewed using polarized glasses.
Navigation: None.
Object manipulation: None.
Video content: Three 30-sec sections selected based on the amount of motion they contained.
Training: 3-min practice trial.
Experimental task: View video clips, providing continual reporting of presence.

Participants:		12 students; 6 males; mean age 22 years.
Study design:		Within-subjects.
Presence measures:		Hand-held slider ratings sampled at 5 Hz.
Findings:	(1)	Used of stereopsis was associated with significantly more presence.
	(2)	Observer motion was associated with significantly more presence than minimal camera motion.

[Freeman 1999 (2)] Freeman, J., Avons, S. E., Pearson, D. E., and Ijsselsteijn, W. A. (1999). Effects of sensory information and prior experience on direct subjective ratings of presence. *Presence, 8* (1), 1–13.

Factors:		Stereopsis (present, absent), camera motion (observer, scene, minimal).
Computing platform:		Two Panasonic M2 (A750-B) video projectors.
Visual display:		AEA Technology 20-in. stereoscopic display consisting of 2 BARCO CPM 2053 color monitors, viewed using polarized glasses.
Navigation:		None.
Object manipulation:		None.
Video content:		Three 30-sec sections selected based on the amount of motion they contained.
Training:		3-min practice trial.
Experimental task:		View video clips, providing continual reporting of presence.
Participants:		12 students; 6 males; mean age 25 years. Performed pre-rating of the continuous interest they had in the video sequences.
Study design:		Within-subjects.
Presence measures:		Hand-held slider ratings sampled at 5 Hz.
Findings:	(1)	Stereopsis had no significant relationship with presence.
	(2)	Camera motion had a significant relationship with presence and a significant interaction with stereopsis.
	(3)	*Stereopsis and camera motion had no relationship with ratings of interest.*

[Freeman 1999 (3)] Freeman, J., Avons, S. E., Pearson, D. E., and Ijsselsteijn, W. A. (1999). Effects of sensory information and prior experience on direct subjective ratings of presence. *Presence, 8* (1), 1–13.

Factors:		Stereopsis (present, absent), camera motion (observer, scene, minimal), training (presence, interest, three-dimensionality).
Computing platform:		Two Panasonic M2 (A750-B) video projectors.
Visual display:		AEA Technology 20-in. stereoscopic display consisting of 2 BARCO CPM 2053 color monitors, viewed using polarized glasses.
Navigation:		None.
Object manipulation:		None.
Video content:		Three 30-sec sections selected based on the amount of motion they contained.
Training:		3-min practice trial.
Experimental task:		View video clips, providing continual reporting of presence.
Participants:		72 participants; 36 males; mean age 24 years.
Study design:		Within-subjects.
Presence measures:		Hand-held slider ratings sampled at 5 Hz.
Findings:	(1)	Use of stereopsis was associated with significantly higher presence ratings.
	(2)	Camera motion had no significant relationship with presence but a significant interaction with training group.
	(3)	Participants trained in 3D rating gave significantly higher presence ratings.

[Garau 2003a] Garau, M., Slater, M., Vinayagamoorthy, V., Brogni, A., Steed, A., and Sasse, M. A. (2003a). The impact of avatar realism and eye gaze control on perceived quality of communication in a shared immersive virtual environment. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems 2003,* Ft. Lauderdale, USA, April, 529–536. See also Garau, M. (2003b). *The impact of avatar fidelity on social interaction in virtual environments*. Doctoral thesis, University College London (UCL), London, UK, Department of Computer Science, See also Vinayagamoorthy, V., Garau, M., Steed, A., and Slater, M. (2004). An eye gaze model for dyadic interaction in an immersive virtual environment: practice and experience. *Computer Graphics, 23* (1), 1–111.

Factors:		Behavioral realism (inferred gaze, random gaze), photorealistism (photorealistic and gender-specific, stick-like), visual display (4-sided Cave, HMD).
Computing platform:		For Trimension ReaCTor system: SG Onyx2 with eight 300-MHz R12000 MIPS processors, 8 GB RAM and 4 InfiniteReality2 graphics pipes. For HMD system: SG Onyx with twin 196-MHz MIPS R10000 processors, InfiniteReality graphics, and 192 MB main memory. Software implemented on derivative of DIVE 3.3×. Avatars humanoid animation (H-Anim) compliant.
Visual display:		One participant of each pair used a Trimension ReaCTor, with three 3 × 2.2 m walls and a 3 × 3 m floor, and CrystalEyes stereo glasses. Partner used a Virtual Research V8 HMD with resolution 640 × 480 × 3, FOV 60º diagonal at 100% overlap.
Tracking:		Head and hand tracking using InterSense IS-900 or Polhemus FASTRAKs.
Navigation:		Hand-held device with 4 buttons (disabled) and joystick, or 5 button 3D mouse.
Object manipulation:		None.
Virtual world:		Two large training rooms connected to a smaller meeting room between them. Self-representation provided for HMD participants. Avatars had identical functionality, with body movement based on participant's head and hand movements. For the inferred gaze condition, avatars used a "while speaking" and "while listening" eye animation model, with "at partner" gaze consistent with direction of participant's head.
Training:		Navigation training task. Doors from training room into meeting room opened when both participants in a pair felt comfortable.
Experimental task:		Role-playing negotiation task, where each pair was a mayor and a baker whose families were involved in a potentially volatile situation. Goal to reach a mutually acceptable conclusion within 10 min.
Participants:		48 BT Exact laboratory employees, grouped into same-gender pair; age range under 21 to over 50.
Study design:		Between-groups.
Presence measures:		5-item SUS Questionnaire, 5-item social presence questionnaire, 2-item co-presence questionnaire, 5-item social presence questionnaire.
Person-related meas.:		Social Avoidance and Distress (SAD) social anxiety questionnaire, age, VE experience, VE knowledge, gender.
Task-related measures:		Quality of communication questionnaire with subscales: Face-to-face, Involvement, 2-item Co-presence (see above), Partner Evaluation. *Rating of real and human-likeness of avatar, rating of understanding of partner's behavior and attitude.*
Findings:	(1)	Behavioral realism and photorealism had a significant relationship with social presence and co-presence. Also a significant interaction relationship with social presence and co-presence, with the higher realism avatar used with inferred gaze yielding more presence; similarly on Face-to-face and Partner evaluation scores.
	(2)	Behavioral realism and photorealism had no significant relationship with SUS scores.
	(3)	Visual display had no significant relationship with co-presence.

(4) Age had a significant positive correlation with quality of communication social presence, co-presence, and SUS scores.
(5) SAD scores had no significant correlation with quality of communication co-presence, but a significant negative correlation with social presence, co-presence, and SUS scores.
(6) Gender had no significant correlation with any presence measure.
(7) VE experience had a significant negative correlation with SUS scores. VE knowledge had a significant positive correlation.
(8) Social presence had a significant positive correlation with SUS scores.
(9) VE experience had a significant, negative correlation with perceived avatar fidelity.
(10) Behavioral realism and photorealism had a significant interaction association with ratings of humanness of avatar and understanding of partner.

[Garau 2003b (1)] Garau, M. (2003b). *The impact of avatar fidelity on social interaction in virtual environments*. Doctoral thesis, Department of Computer Science, University College London (UCL), London, UK. See also Garau, M., Slater, M., Pertaub, D.-P., and Razzaque, S. (2005). The responses of people to virtual humans in an immersive virtual environment. *Presence, 14* (1), 104–116.

Factors: Agent responsiveness (talking and other behaviors, change position and gaze behavior, moving (e.g., turn page), static)).
Computing platform: SG Onyx 2 with eight 300-MHz R12000 MIPS processors, 8 GB RAM and 4 InfiniteReality2 graphics pipes. DIVE-based software. Thought Technologies ProComp+ system for physiological monitoring and associated PC. Agents based on Criterion Software RenderWare models.
Visual display: Trimension ReaCTor, with three 3×2.2 m walls and 3×3 m floor, and CrystalEyes shutter glasses.
Tracking: Head tracking using InterSense IS-900.
Navigation: Using joystick with 4 buttons.
Object manipulation: None.
Virtual world: Library with three male and two female agents seated around a central table with books and papers. Several bookcases against the walls, book tables, and book trolleys. Agents exhibited gaze and postural behaviors. Static agents were frozen in a reading pose. Moving agents exhibited movements such as turning a page but not did respond to the participant. Responsive agents also changed position and engaged in gaze behavior when participant approached. For talking agents, the first agent approached would also speak to the participant (in a foreign language). Collision detection on library walls only.
Training: Practice moving through virtual space in an area adjacent to the library.
Experimental task: Explore the space preparatory to later reporting on experience. 4 min allowed.
Participants: 41 participants; 24 males.
Study design: Between-groups.
Presence measures: 5-item SUS questionnaire, 5-item co-presence questionnaire, 5-item self-behavior questionnaire, 4-item perceived agent awareness questionnaire, Δheart rate, Δskin conductance.
Person-related meas.: SAD social anxiety questionnaire, gender, computer usage, VR experience.
Findings:
(1) Agent responsiveness had no significant relationship with presence.
(2) Agent responsiveness had a significant relationship with only 1 item of co-presence. When computer usage is considered, agent responsiveness had a significant effect, with more presence reported for the responsive condition than the static condition and participants with more computer usage reporting less presence.
(3) Presence had a significant positive correlation with co-presence.

(4) Agent responsiveness had a significant relationship with self-behavior, with more social presence indicated for the responsive condition than for the static condition. SAD scores had a significant positive correlation with 1 item only.

(5) Agent responsiveness had a significant relationship with perceived agent awareness, with more social presence indicated for talking and responsive conditions than for moving and static conditions. Gender and VR experience also had significant effects, with females and those with prior VR experience more likely to perceive agents as being aware.

(6) Gender and computer usage had no significant correlation with SUS scores or co-presence.

(7) Significant change in heart rate occurred only for participants in the responsive condition. Significant change in skin conductance occurred for participants in the talking, responsive, and moving conditions.

[Garau 2001] Garau, M., M. Slater, S. Bee, and Sasse, M. A. (2001). The Impact of Eye Gaze on Communication using Humanoid Avatars." *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems 2001,* Seattle, USA, March–April, 309–316. See also Garau, M., Slater, M., Vinayagamoorthy, V., Brogni, A., Steed, A., and Sasse, M. A. (2003). The impact of avatar realism and eye gaze control on perceived quality of communication in a shared immersive virtual environment. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems 2003,* Ft. Lauderdale, USA, April, 529–536.

Factors:	Behavioral realism (video, inferred gaze, random gaze, audio only).
Computing platform:	Dell Dimension XPST 550 (Pentium III) with GeForce 256 chipset, Gulillemot 3D Prophet video card, Creative AWE32 sound card, running Windows 98. Compaq AP400 PIII 500 with GeForce 256 chipset, Elsa Gloria 2 video card, integrated sound, running Windows 98.
Visual display:	Video tunnel link providing face-on, head-and-shoulders view of partner, used a 21-in. Sony PVM-2130QM video monitor.
Audio display:	Sennheiser HD265 headphones. Sound recorded using an AKG C747 microphone placed on desk.
Tracking:	Head tracking using Polhemus ISOTRAK II.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Empty meeting room. In random gaze condition, timings and directions for avatar's head and eye movement randomly generated. In inferred gaze condition, eye animations based on audio stream based on "while speaking" and "while listening" modes based on dyadic conversation research.
Experimental task:	Role-playing task. One participant played role of mayor and the other that of a baker whose families had a conflict. Task was to reach a mutually acceptable solution within 10 min.
Participants:	100 BT Exact laboratory employees, grouped into same-gender pairs and matched for age.
Study design:	Between-groups.
Presence measures:	2-item co-presence questionnaire.
Person-related meas.:	Gender.
Task-related measures:	Quality of communication questionnaire with subscales: Face-to-face, Involvement; co-presence (see above); partner evaluation.

Findings:

(1) Video condition had significantly higher co-presence scores than other conditions, followed by audio only and then inferred gaze.

(2) Gender had no significant relationship with social presence.

(3) Behavioral realism had a significant relationship with quality of communication Face-to-face scores, with the video and inferred gaze conditions yielding more realistic conversation than each of the random gaze and neutral conditions. It also had a significant relationship with Involvement subscale, with the random gaze

condition yielding less involvement than other conditions. For Partner Evaluation subscale, video condition scores were significantly higher than those in the random gaze condition, which scores were significantly than in either the random gaze or neutral conditions.

[Gerhard 2005] Gerhard, M., Moore, D., and Hobbs, D. (2005). Close encounters of the virtual kind: Agents simulating copresence. *Applied Artificial Intelligence, 19,* 393–412. See also Gerhard, M., Moore, D., and Hobbs, D. (2004). Embodiment and copresence in collaborative interfaces. *International Journal of Human-Computer Studies, 61,* 453–480.

Factors:	Co-presence (conversational agent to simulate co-presence, no agent).
Computing platform:	Web-based.
Object manipulation:	None.
Virtual world:	Art gallery with 1 reception room and 3 exhibition rooms. 45 artworks taken from the Axis database (the British National Artists Register). Participants in the experimental condition encountered a virtual agent in the gallery, simulating the presence of another gallery visitor. This agent, called Art-Fairy, had a humanoid representation, exhibited gestures, and had general conversational skills and a limited knowledge of the environment.
Experimental task:	In each exhibition room, select one favorite artwork.
Participants:	20 participants randomly selected from students, school teachers, and visual artists registered in the Axis database.
Study design:	Between-groups.
Presence measures:	20-item questionnaire with subscales Immersion, Involvement, Awareness, CVE, Interface.
Person-related meas.:	Immersive Tendencies Questionnaire, experience with VEs and visual arts.
Findings: (1)	Participants with the conversational agent gave significantly higher presence (Immersion, Involvement, and Awareness) scores.

[Gerhard 2001a] Gerhard, M., Moore, D. J., and Hobbs, D. J. (2001a). Continuous presence in collaborative virtual environments: Towards the evaluation of a hybrid avatar-agent model for user representation. *Proceedings of the 3rd International Workshop on Intelligent Virtual Agents,* Madrid, Spain, September, 137–155. See also Gerhard, M., Moore, D. J., and Hobbs, D. J. (2001b). An experimental study of the effect of presence in collaborative virtual environments. *Proceedings of the British Computer Society Conference on Intelligent Agents, Mobile Media, and Internet Applications*, Bradford, West Yorkshire, UK.

Factors:	Avatar realism (animated humanoid, animated cartoon-style, basic shapes).
Computing platform:	Avatars created using Avatara and Cybertown. Supported on Web using Blaxxun Virtual World Platform community server.
Visual display:	Desktop monitors.
Object manipulation:	None.
Virtual world:	Art gallery using basic shapes for defining the geometry of the room and picture frames. Made available on the Web with avatar and chat interaction.
Experimental task:	Unanimously and collaboratively identify the art style (Cubist, Abstract, Naïve, Celtic, Psychedelic, Surreal) of a 4 contemporary artworks.
Participants:	27 participants, grouped into threes based on experience and immersive tendencies scores.
Study design:	Between-groups.
Presence measures:	22-item presence questionnaire focused on immersion, communication, involvement, awareness, and variables related to the nature of the environment and user interface. Web based.
Findings: (1)	Humanoid and cartoon-style avatars conditions had significantly higher presence scores than the basic shapes condition.

[Guadagno 2006 (1)] Guadagno, R. E., Blascovich, J., Bailenson, J. N., and McCall, C. (2006). Virtual humans and persuasion: The effects of agency and behavioral realism. *Media Psychology, 10* (1).

Factors:		Virtual human behavioral realism (mutual gaze and blinking and moving lips, no head/lip movement and no blinking), virtual human gender (male, female), participant gender (male, female).
Computing platform…		
Object manipulation:		As in [Bailenson 2001a].
Virtual world:		Simple room with a male or female agent that were selected (from a pre-tested sample) to be slightly above average in ratings of perceived attractiveness, friendliness, likeability, and intelligence, and for whom there were no gender differences in participants' ratings.
Experimental task:		Listen to another student's (favorable) opinion on a potential new university security policy. Not told whether avatar or agent.
Participants:		65 undergraduates, selected on basis of agreement, interest, and knowledge on the topic.
Study design:		Between-subjects.
Presence measures:		4-item social presence questionnaire.
Task-related measures:		*4-item rating of realism of virtual person*, *attitudes scale (covering the security policy and impression of virtual human)*, *quality of presentation rating*.
Findings:	(1)	Participants reported significantly more social presence for the high behavioral realism condition.
	(2)	Participant gender and virtual human gender had no significant relationship with social presence scores.
	(3)	*Participants rated the female agent as significantly more likeable; attributed to females who showed an ingroup favoritism effect.*
	(4)	*Participants rated the female agent as having a significantly higher presentation quality (again driven by female ingroup favoritism).*

[Guadagno 2006 (2)] Guadagno, R. E., Blascovich, J., Bailenson, J. N., and McCall, C. (2006). Virtual humans and persuasion: The effects of agency and behavioral realism. *Media Psychology, 10* (1).

Factors:		Agency (human-controlled, computer-controlled), virtual human behavioral realism (breaking eye-contact and mutual gaze and blinking and moving lips, no head/lip movement and no blinking), virtual human gender (male, female), participant gender (male, female).
Computing platform…		
Object manipulation:		As in [Bailenson 2001a].
Virtual world:		As in [Guadagno 2006 (1)], except in the high behavioral realism condition, the virtual human only tracked the gaze of the participant within a 15º FOV and broke and reestablished eye-contact at random intervals.
Experimental task:		Listen to another's opinion on a potential new university security policy. Participants told either that virtual human was human or computer controlled.
Participants:		174 undergraduates; 85 males.
Study design:		Between-subjects.
Presence measures:		4-item social presence questionnaire.
Task-related measures:		*Attitudes scale (covering the security policy and impression of virtual human)*, *quality of presentation rating*.
Findings:	(1)	Participants reported significantly more social presence for the high behavioral realism condition.
	(2)	Participants who believed they were interacting with a human-controlled avatar reported significantly more social presence.

(3) Participants reported significantly more social presence for female virtual human believed to be an avatar than when believed to be an agent.

(4) Agency had an interaction with virtual human gender, such that for male virtual humans, attitude change was significantly larger when participants believed virtual human was human controlled.

(5) Virtual human gender, participant gender, and behavioral realism had a significant interaction, such that male participants reported more attitude change in the high behavioral realism condition when the virtual human was male than when the virtual human was female.

(6) Virtual female human was rated as significantly more likeable than the male when perceived as human controlled.

(7) Participants rated the female agent as having a significantly higher presentation quality (again driven by female ingroup favoritism).

[Guger 2004] Guger, C., Edlinger, G., Leeb, R., and Pfurtscheller, G. (2004). Heart-rate variability and event-related ECG in virtual environments. *Proceedings of the 7th Annual International Workshop on Presence*, Valencia, Spain, October, 240–245.

Computing platform: DIVE system.
Visual display: 4-sided Cave with ~ 3 m^3 area.
Virtual world: Virtual bar with a barman, one couple standing near bar and another couple sitting across room. Couples aware of participant's location and often address remarks to him (~ 30 sentences). 2 songs played in background and background chatter. 4 BIPs (whiteouts lasting for 2 sec each) distributed uniformly in time. 5 min.
Training: Simple navigation task.
Experimental task: Experience bar.
Participants: 21 participants.
Presence measures: Event-related electrocardiogram (ECG) (captured for speaking events and BIPs using g.tec from Guger Technologies OEG, Austria), heart-rate variability (HRV).
Findings:
(1) Significant difference in HRV between training and experimental phases.
(2) BIPs were related to a significant difference in HRV.
(3) Speaking events were related to a significant difference in event-related ECG.

[Heldal 2005] Heldal, I., Schroeder, R., Steed, A., Axelsson, A.-S., Spante, M., and Wideström, J. (2005). Immersiveness and symmetry in copresent scenarios. *Proceedings of IEEE Virtual Reality 2005*, Bonn, Germany, March, 171–178.

Factors: Type of environment (real, immersive projection technology (IPT) to HMD, IPT-to-desktop, desktop-to-desktop, IPT-to-IPT)).
Computing platform: One IPT system used SG Onyx2 InfiniteReality with fourteen 250-MHz MIPS R10000 processors, 2 GB RAM and 3 graphics pipes. Other IPT system used SG Onyx2 with eight 300-MHz R12000 MIPS processors, 8 GB RAM and 4 InfiniteReality2 graphics pipes. IPT systems used DIVE software. HMD system used PTC Division Mockup software. Desktop system used SG O2 with 1 MIPS R10000 processor and 256 MB RAM, dVise 6.0 software. Robust Audio Tool for audio communication. Network lag < 180 ms.
Visual display: VR-CUBE 3 × 3 × 3 m with CrystalEyes shutter glasses; Trimension ReaCTor 2 2.8 × 2.2 m walls and 2.8 × 2.8 m floor with CrystalEyes shutter glasses; n-Vision Datavisor 10× with 640 × 480 resolution, FOV 87º H x 50º V; 19-in. monitor.
Audio display: Wired headset with microphone.
Tracking: Head and hand tracking using Polhemus and InterSense devices (IPT).
Navigation: Using 3D wand or joystick (IPT), pinch gloves (HMD), mouse (desktop).
Object manipulation: Using 3D wand or joystick (IPT), pinch gloves (HMD), mouse (desktop).

Virtual world: Room with cubes. Participants represented by simple avatar with jointed arm. Participants in immersive conditions saw only virtual hand.
Training: Practice in marking and picking up objects, navigation, use of devices, and use of audio. 5 to 10 min.
Experimental task: Working in pairs, solve puzzle involving eight 30 × 30 × 30 cm blocks with different colors on different sides by arranging blocks so that each side of assembled blocks displays a single color. 20 min allowed.
Participants: 220 participants, grouped into pairs.
Study design: Between-subjects.
Presence measures: 2-item SUS questionnaire, 2-item co-presence questionnaire.
Task-related measures: *Rating own and partner's contribution to task in three areas, collaboration questionnaire*, *usability questionnaire*.
Performance measures: *Time to complete*.
Findings:
(1) Type of environment had a significant relationship with presence only for the IPT-to-desktop condition, with more presence reported for IPT.
(2) Participants in the IPT-to-IPT and IPT-to-HMD conditions gave significantly higher co-presence scores than those in IPT-to-desktop and desktop-to-desktop conditions.
(3) Presence had no significant correlation with co-presence.
(4) Type of environment had no significant relationship with collaboration.
(5) Type of environment had a significant relationship with nonverbal contribution to task in the IPT-to-HMD and IPT-to-desktop conditions.
(6) Type of environment had no significant association with usability for the IPT-to-desktop condition.

[Hendrix 1996a (1)] Hendrix, C., and Barfield, W. (1996a). The sense of presence within auditory virtual environments. *Presence, 5* (3), 290–301.

Factors: Audio cues (spatialized sound, no sound).
Computing platform: SGI Indigo Extreme workstation. Crystal River Engineering Beachtron audio spatializer card in 386 PC.
Visual display: GE-610 6 × 8 ft rear projection screen, stereoscopic viewing using StereoGraphics Corporation CrystalEyes shutter glasses. Images generated with 1280 × 512 pixel resolution. Subject seated to achieve 90° horizontal field of view (HFOV), 50° GFOV.
Audio display: Yamaha YH-1 orthodynamic headphones, with radio signal delivered via a Realistic receiver/amplifier. Soda machine sounds obtained using an Ensoniq digital sound sampler. Sounds uncorrelated with actions in VE.
Tracking…
Experimental task: As in [Hendrix 1996a (1)].
Participants: 16 university students; 14 males; mean age 29.9 years. 4 participants had participated previously in presence-related studies.
Study design: Within-subjects.
Presence measures: 3-item questionnaire, including overall rating, 1 item on sense of "being there," 1 item on realism of virtual world.
Findings:
(1) Audio cues had a significant relationship with each measure of presence, with increased presence reported for spatialized sound.
(2) Realism had a significant positive correlation with overall presence rating and sense of "being there."

[Hendrix 1996a (2)] Hendrix, C., and Barfield, W. (1996a). The sense of presence within auditory virtual environments. *Presence, 5* (3), 290–301.

Factors: Audio cues (spatialized sound, non-spatialized sound).

Computing platform…

Study design: As in [Hendrix 1996b (1)].

Presence measures: 5-item questionnaire, including overall rating, 1 item on sense of "being there," 1 item on realism of virtual world, 1 item on realism of interaction with sound sources, 1 item on emanation of sound from specific locations.

Findings:
(1) Spatialized audio cues were associated with significantly higher scores for each measure of presence.
(2) Realism in appearance, interaction, localization had a significant positive correlation with overall presence rating and sense of "being there."

[Hendrix 1996b (1)] Hendrix, C., and Barfield, W. (1996b). Presence within virtual environments as a function of visual display parameters. *Presence, 5* (3), 274–289.

Factors: Head tracking (present, absent).

Computing platform: SGI Extreme workstation.

Visual display: GE-610 6 × 8 ft rear projection screen, stereoscopic viewing using StereoGraphics Corporation CrystalEyes shutter glasses. Images generated with 1280 × 512 pixel resolution, standard conditions were GFOV 50°. (Shutter glasses also worn in monoscopic condition with disparity set to zero.) Eyepoint elevation 110 cm. Subject seated/standing so position subtended a 90° FOV.

Tracking: Polhemus 3Space FASTRAK for head tracking.

Navigation: Standard mouse placed on table in front of subject.

Object manipulation: None.

Virtual worlds: 10 × 10 m virtual room with checkerboard patterned floor and several familiar objects such as tables and chairs, a bookshelf, a soda machine, a photocopier machine, and paintings.

Experimental task: Navigate around room to become familiar with the environments in order to answer questionnaire previously made available. No time limit.

Participants: 12 university students; 6 males; mean age 27 years. Same participants as used in [Hendrix, 1996a (2), (3)].

Study design: Within-subjects.

Presence measures: 4-item questionnaire, including overall presence rating, 1 item on sense of "being there," 1 item on realism, 1 item on responsiveness.

Findings:
(1) The use of head tracking was associated with significantly higher scores for each measure of presence.
(2) The use of head tracking was associated with significantly higher scores for realism and responsiveness.
(3) Realism of interaction and response had a significant positive correlation with presence rating and sense of "being there."

[Hendrix 1996b (2)] Hendrix, C., and Barfield, W. (1996b). Presence within virtual environments as a function of visual display parameters. *Presence, 5* (3), 274–289.

Factors: Stereopsis (present, absent).

Computing platform…

Study design: As in [Hendrix 1996a (1)].

Presence measures: 5-item questionnaire, including overall presence rating, 1 item on sense of "being there," 1 item on realism of response, 1 item on realism of depth/volume, 1 item an ability to reach into VE.

Findings:
(1) Stereopsis was associated with significantly higher scores for each measure of presence.
(2) Stereopsis was associated with significantly higher scores for rating of realism of depth/volume and ability to reach into VE but had no significant relationship with rating of realism of response.

(3) Realism of response, realism of depth/volume, and ability to reach into VE had a significant positive correlation with presence rating and sense of "being there."

[Hendrix 1996b (3)] Hendrix, C., and Barfield, W. (1996b). Presence within virtual environments as a function of visual display parameters. *Presence, 5* (3), 274–289.

Factors: Geometric FOV (90°, 50°, 10°).
Computing platform…
Study design: As in [Hendrix 1996a (1)], except used 3 virtual worlds.
Presence measures: 6-item questionnaire, including overall rating, 1 item on sense of "being there." Remainder consisted of 1 item on realism of virtual world, 1 item on object compression/magnification, 1 item on narrowness/width, 1 item on proportional correctness.
Findings:
(1) GFOV had a significant relationship with each measure of presence, realism, and proportional correctness with reported presence higher for GFOV 50° than 10° and for GFOV 90° than 10°.
(2) GFOV had no significant relationship with perceived object compression/magnification and narrowness/width.
(3) Realism and perception of proportionally correct had a significant positive correlation with presence rating and sense of "being there"; perception of compression/magnification and view had no significant correlation with either measure of presence.

[Hoffman 1999] Hoffman, H. G, Hollander, A., Schroder, K., Rousseau, S., and Furness III, T. (1999). Physically touching, and tasting virtual objects enhances the realism of virtual experiences. *Virtual Reality, 3,* 226–234.

Factors: Olfactory cues (biting candy bar, imagining biting candy bar).
Computing platform: Division's ProVision 100 system.
Visual display: Division's dVisor HMD with FOV 40° V × 105° H, 40° overlap.
Tracking: Polhemus sensors attached to fingerless bicycle glove and to real candy bar.
Navigation: None.
Object manipulation: Using 3D wand.
Virtual world: Division's KitchenWorld demo with virtual candy bar. Self-representation as virtual hand.
Experimental task: Examine kitchen for 1 min. Then close eyes while experimenter tears off part of the wrapper and places candy bar in participant's hand. Open eyes and smell candy bar. In biting condition, take a bite out of the candy bar; in imagine condition, only imagine taking a bite.
Participants: 21 university students.
Presence measures: Questionnaire.
Findings:
(1) Olfactory cues were associated with significantly presence scores.

[Hoffman 1998] Hoffman, H. G., Groen, J., Prothero, J., and Wells, M. J. (1998). Virtual chess: Meaning enhances users' sense of presence in virtual environments. *International Journal of Human-Computer Interaction, 10* (3), 251–263.

Factors: Meaning (meaningful chess position, meaningless chess position), task expertise (nonchess player, weak player, strong player, tournament-level player).
Computing platform: Division ProVision 100 reality engine.
Visual display: Division's dVisor HMD with FOV 40° V × 105° H, 40° overlap.
Tracking: Polhemus 6 DOF head and mouse tracking.
Navigation: Only by moving head to change coordinates and get a closer view of chessboard.

Object manipulation:		Using 3 DOF mouse.
Virtual world:		Virtual chess board on a wooden floor. Tartakower and DuMont's 16 middle game positions were used as meaningful stimuli. The chess pieces from each middle game were rearranged in a random manner to create 16 meaningless positions.
Training:		Familiarization with VEs and interface devices by 5 min of playing Division's SharkWorld game.
Experimental task:		Each participant presented with 16 chess positions—each labeled meaningful or meaningless—and told to memorize the positions. 1 min for each set of positions.
Participants:		33 participants from a university and a city chess club.
Study design:		Within-subjects for meaning, between-subjects for chess expertise.
Presence measures:		4-item questionnaire.
Task-related measures:		Memory accuracy on identifying 16 studied chessboard positions (8 meaningful and 8 meaningless) among 32 presented positions.
Findings:	(1)	Meaningful chess position was associated with significantly higher presence scores.
	(2)	Task expertise had no significant main effect on presence. A significant interaction was found with meaningfulness, such that nonchess players showed no significant effect for meaningfulness but all other classes of players showed a significant positive effect of meaningfulness on presence.
	(3)	*Each of meaningfulness and task expertise had a significant positive association with memory accuracy. A significant interaction between these was found, such that tournament players were significantly more accurate on meaningful positions, whereas no significant difference was found for all other classes of task expertise.*

[Hoffman 1996] Hoffman, H., Groen, J., Rousseau, S., Hollander, A., Winn, W., Wells, M., and Furness III, T. (1996). *Tactile augmentation: enhancing presence in virtual reality with tactile feedback from real objects*. Paper presented at the 8th Annual Meeting of the American Psychological Society, San Francisco, USA. Available: http://www.hitl.washington.edu/publications/p-96-1/

Factors:		Haptic cues (mixed reality with physical objects, virtual objects only).
Computing platform:		Division ProVision 100 system.
Visual display:		Division dVisor HMD with FOV 40° V × 105° H, 40° overlap.
Tracking:		Position sensor attached to hand.
Object manipulation:		3 DOF mouse with trigger button used to "pick-up" object.
Virtual world:		Included models of 8 real items (e.g., butter knife) with texture mapping. Self-representation as virtual hand.
Experimental task:		Observe some objects, observe and touch other objects.
Participants:		14 university students.
Study design:		Within-subjects.
Presence measures:		5-item questionnaire.
Findings:	(1)	Haptic cues were associated with significantly higher presence scores.

[Hofman 2001] Hofman, J., Jäger, T. J., Deffke, T., and Bubb, H. (2001). Effects of presence on spatial perception in virtual environments. *Proceedings of the 4th Annual International Workshop on Presence,* Philadelphia, USA, May.

Factors:	Immersion factors (high, low), pictorial realism (high, low).
Computing platform:	SGI Onyx2 graphics engine.
Visual display:	5-sided rear projection system with 3 walls, ceiling, and floor, each 2.5 m. Screen resolution 1020 × 1020. Refresh rate 114 Hz. Viewed using StereoGraphics CrystalEyes shutter glasses. Display adjusted for individual's IPD.
Audio display:	None.
Tracking:	Head tracking using Ascension Technology's 6 DOF MotionStar.
Navigation:	None.

Object manipulation:	Tubular hand-held device used for immersion scaling tasks by pressing a button and simultaneously rotating the device.
Virtual world:	Virtual front half of a passenger car interior, with a real driving seat and steering wheel. High-realism version provided a high level of 3D detailing and was completely textured in color; low-realism version details such as switches, safety belts were omitted, no textures were used, uniform colors were used. Immersion factors were frame rate, interactivity, duration of exposure, vividness of scene, mental priming, real-world ambient light, real-world background noise, and communication with instructor.
Training:	None.
Experimental task:	While seated in the real driver's car, provide verbal directions to adjust the size of the virtual car cockpit until it matched the memorized size of an actual car cockpit previously seen. 3 different scaling procedures used in 3 sessions: uniform 3D scaling, one-dimensional (1D) horizontal scaling, partial 1D vertical scaling. Presence questionnaire completed while immersed.
Participants:	77 participants (mainly passenger car development engineers); 68 males; age range 20 to 60.
Study design:	Between-subjects.
Presence measures:	Modified IPQ.
Performance measures:	Size estimation error for each type of scaling.
Findings: (1)	IPQ Spatial Presence and Reality Appraisal subscales had a significant correlation with size estimation error when the uniform scaling method was used. IPQ Involvement subscale had a significant correlation with size estimation error when partial vertical scaling method was used.

[Huijnen 2004] Huijnen, C. A. G. J., Ijsselsteijn, W. A., Markopoulos, P., and de Ruyter, B. (2004). Social presence and group attraction: Exploring the effects of awareness systems in the home. *Cognition, Technology and Work, 6* (1), 41–44.

Factors:	Level of detail (full video, sketchy visual, no visualization), viewer type (group, alone).
Visual display:	TV.
Tracking:	None.
TV:	Sports event program, 1974 soccer game of Dutch national team. Visualization of friends (depending on condition), no audio connection.
Experimental task:	Watch show with visualization of friends depending on condition.
Participants:	34 male participants, grouped in threes (one group of two) with friends.
Study design:	Within-subjects for type of visualization, between-subjects for viewer type.
Presence measures:	Slightly adapted IPO Social Presence Questionnaire (IPO-SPQ).
Task-related measures:	*Group Attitude Scale*.
Findings: (1)	Full video was associated with significantly higher IPO-SPQ subjective attitude statements and semantic differential scales than sketchy visual or no visualization.
(2)	Viewer type had no significant relationship with presence.
(3)	*Full video was associated with significantly more group attraction.*

[Hullfish 1996] Hullfish, K. (1996). *Virtual reality monitoring: How real is virtual reality?* Master's thesis, University of Washington, Seattle, Human Interface Technology Laboratory.

Factors:	Environment type (real, virtual, imagined).
Computing platform:	Division ProVision 100 system with dVise software. Geometry created using 3D Studio and Macromodel. Lighting simulated using directional and ambient light, metallic surfaces simulated.
Visual display:	Stereoscopic Division dVisor HMD with FOV 105ºH x 41ºV. Subject's height was simulated. Experimental area curtained off.

Navigation: Using single button on 3D joystick.
Object manipulation: Pointing to objects using virtual hand.
(Virtual) world: Each world had a 12 × 12 ft chessboard in the middle of the floor, and four 14 × 14 × 14 in. identical objects (cubes, half cylinders, 3D "T"s, or 3D triangles) of different colors (red, purple, yellow, and blue) arranged in a pattern on the chessboard. Four sets of 8 worlds were developed. Each arrangement was 1 of 8 distinct, global shapes (e.g., curve, trapezoid). 4 sets of 8 worlds were developed, experienced in either virtual world, real, or imagined condition. (Imagined was the same as the real condition, except objects were not present and had to be imagined based on written instructions.) In the virtual world, ceiling and stone walls were texture mapped with photographs from RE, details included electrical outlets, conduits, and switches. Self-representation as virtual hand.
Training: Play Division's SharkWorld game to become familiar with the equipment and navigational controls. Two practice trials in each type of environment.
Experimental task: In the study phase, for each of 24 worlds, memorize (and later report) the spatial configuration of the 4 objects and the position of this global shape on the chessboard while navigating a pre-defined path and pointing to each object as they passed it. Then, play in a Chemistry World VE for 15 min. In the test phase, for each of 32 worlds presented on a PC, determine whether that world had been seen previously and, if so, in what type of environment.
Participants: 16 university community participants; 6 males; age range 20 to 38. No experience in VE technology.
Study design: Within-subjects.
Presence measures: Virtual Reality Monitoring, Memory Characteristic Questionnaire (MCQ).
Task-related measures: *Item on MCQ concerned with cognitive effort*.
Performance measures: *Items on MCQ concerned with rating memories of real, virtual, and imagined environments*.
Findings:
(1) Real environments were associated with significantly higher ratings of the "sense of being there" and "being surrounded by objects" than virtual or imagined environments.
(2) Environment type had no significant relationship with the "sense of visiting rather than seeing an environment," on "remembering being a spectator rather than a participant," or "awareness of my body."
(3) For old/new recognition, environment type had no significant relationship with frequency with which worlds were misrecognized as new. Participants missed new worlds significantly more than frequently than any other worlds from another origin and were as likely to miss virtual and imagined worlds than to identify them correctly as old.
(4) For correct identification of origin, environment type had a significant effect, with virtual worlds identified correctly less frequently than real, imagined, or new worlds. These worlds more frequently assigned as real rather than imagined or new.
(5) Environment type had a significant relationship with cognitive effort, with experience in imagined worlds being rated as more difficult, virtual less difficult, real easiest. Real and virtual memories were rated as the most similar.

[Ijsselsteijn 2004a] Ijsselsteijn, W. A., de Kort, Y. A. W., Bonants, R., Westerink, J., and de Jager, M. (2004a). Virtual cycling: Effects of immersion and a virtual coach on motivation and presence in a home fitness application. *Proceedings Virtual Reality Design and Evaluation Workshop 2004*, Nottingham, UK, January, 22–23. See also Ijsselsteijn, W. A., de Kort, Y. A. W., Westerlink, J., de Jager, M., and Bonants, R. (2004b). Fun and sports: Enhancing the home fitness experience. In M. Rauterberg (Ed.), Entertainment Computing – ICEC 2004, 3rd International Conference, Eindhoven, The Netherlands, September, *Lecture Notes in Computer Science, 3166,* 46–56.

Factors: Interaction/immersion (high, low), virtual coach (present, absent).

Visual display:	Wall-mounted screen.
Navigation:	In high immersive condition, using bicycle handlebars and biking velocity.
Object manipulation:	None.
Virtual world:	Highly immersive world provided visualization of a person cycling on a racing bicycle through a landscape. Every minute, a female virtual coach would encourage participants to do better, tell them they were doing great, or tell them to slow down a little, based on participant's measured heart rate. In the low immersive condition, the presentation was an abstract picture of a racetrack in bird's eye view, with a dot indicating the position of the bicycle. The participant was seated on racing cycle placed on a training system with variable resistance.
Experimental task:	Bicycle through environment. 4 sessions (ITC-SOPI and Intrinsic Motivation Inventory (IMI) completed after each session)).
Participants:	24 Philips Research Eindhoven employees; 12 males; mean age 41.3 years. None engaged in frequent physical exercise.
Study design:	Within-subjects.
Presence measures:	ITC-SOPI.
Task-related measures:	IMI with 6 subscales, *mean bicycle velocity*.
Findings: (1)	High immersion was associated with significantly higher scores for ITC-SOPI subscales of Spatial Presence, Engagement, and Ecological Validity and with lower scores for Negative Effects.
(2)	Virtual coach was associated with significantly higher scores on Spatial Presence and significantly lower scores on Negative Effects.
(3)	ITC-SOPI Spatial Presence, Engagement, and Ecological Validity subscale scores had a significant correlation with IMI Interest/Enjoyment, Perceived Control, and Pressure/Tension subscale scores.
(4)	*Interaction/immersion had a significant relationship with IMI Interest/enjoyment, Perceived Competence, Value/usefulness, and Perceived Control subscale scores, with high immersion giving increased motivation.*
(5)	*Virtual coach had a significant relationship with IMI Value/Usefulness and Perceived Control subscale scores, with presence of the coach giving increased motivation.*
(6)	*Interaction/immersion had a significant relationship with mean average bicycle velocity, with high immersion yielding increased velocity. Virtual coach had no significant relationship with mean velocity.*

[Ijsselsteijn 2001a] Ijsselsteijn, W., de Ridder, H., Freeman, J., Avons, S. E., and Bouwhuis, D. (2001a). Effects of stereoscopic presentation, image motion, and screen size on subjective and objective corroborative measures of presence. *Presence, 10* (3), 298–311. See also Ijsselsteijn, W. A, Bouwhuis, D. G., Freeman, J., and de Ridder, H. (2002). P-15: Presence as an experiential metric for 3D display evaluation. *Proceedings of the SID 02 Digest,* 252–255. Available: [http://www.ijsselsteijn.nl/papers/SID2002.pdf]. See also Ijsselsteijn, W. A., de Ridder, H., Freeman, J., and Avons, S. E. (2000). *Presence: concepts, determinants, and measurement.* Paper presented at the 3rd International Workshop on Presence, Delft University of Technology, The Netherlands, March.

Factors:	Stereopsis (present, absent), image motion (present, absent), horizontal screen size (50º, 28º).
Computing platform:	PC to control two Panasonic M2 (A750-B) video players and tracker. Custom software.
Visual display:	Curved stereoscopic projection screen 1.9 × 1.45 m, providing FOV 50º H, with polarized glasses.
Tracking:	Ascension Technology's Flock of Birds tracker, placed around participant's neck.
Video sequence:	Moving video comprised 100-sec excerpt from rally car sequence filmed for ACTS MIRAGE *Eye to Eye* documentary using camera mounted on car hood. Motion capable of evoking lateral postural responses. Still video consisted of frame from *Eye to Eye* footage, where camera situated by side of rally track awaiting rally car

	to drive by. Synchronized, nondirectional audio track consisting of sounds from car engine, gear changes, and clattering from stones hitting underside of car. Lower sound intensity used for still video.
Experimental task:	View video. 4 trials.
Participants:	24 students; 11 males; age range 18 to 30; mean age 23.5 years. Height under 1.85 m and stereoacuity ≥ 30 sec-arc or better.
Study design:	Within-subjects for image motion and stereopsis, between-subjects for screen size (with reference to Freeman (2000) data)).
Presence measures:	Rating of presence on visual-analog scale, lateral postural response (data reported on 16 participants).
Task-related measures:	*Rating of vection, rating of involvement, rating of sickness*.
Findings:	(1) Use of stereopsis was associated with a significantly higher rating of presence.
	(2) Image motion had a significant relationship with rating of presence, with more presence reported for moving video scene.
	(3) Screen size had a significant interaction with motion, such that FOV had an effect only for the motion sequence, when more presence was reported for the larger FOV.
	(4) Stereopsis and image motion had no relationship with postural response, although a significant interaction between road type and stereopsis and motion was found for the curved section of the road.
	(5) Presence scores had no significant correlation with postural responses.
	(6) Screen size had no significant correlation with postural response.
	(7) Stereopsis had no significant relationship with rating of vection, involvement, or sickness.
	(8) Image motion had a significant relationship with rating of vection and involvement but not with sickness.
	(9) Screen size had no significant relationship with rating of vection.

[Ijsselsteijn 2001b] Ijsselsteijn, W., Bierhoff, I., and Slangen-de Kort, Y. (2001b). *Duration estimation and presence.* Paper presented at the 4th Annual International Workshop on Presence, Philadelphia, USA, May.

Factors:	Directional information (map, text), range of information (complete route, per subgoal, per decision point).
Computing platform:	Intel Pentium II PC. Sense9 WorldUp software.
Visual display:	17-in. desktop monitor.
Navigation:	Using cursor keys on keyboard.
Object manipulation:	None.
Virtual world:	Included a route navigation system that offered real-time directional information as either text or a map.
Experimental task:	Navigate through a 3D maze. 3 trials.
Participants:	44 students; 32 males; age range 20 to 26.
Study design:	Within-subjects for range of information, between-subjects for directional information.
Presence measures:	4-item presence questionnaire.
Task-related measures:	*Time to complete*, duration estimation, judged speed.
Findings:	(1) Direction information had no significant relationship with presence.
	(2) Duration estimation (corrected for differences in time taken) had no significant correlation with presence.
	(3) Judged speed had a significant positive correlation with presence.
	(4) Duration estimation and judged speed had a significant positive correlation with time to complete.

[Insko 2001 (2)] Insko, B. E. (2001). *Passive haptics significantly enhances virtual environments*. Doctoral dissertation, University of North Carolina, Chapel Hill.

Factors:		Haptic cues (practice in mixed-reality maze, practice in unaugmented virtual maze).
Computing platform:		SGI Onyx2, with 1 InfiniteReality2 Engine with 4 MIPS R12000 processors, 4 raster managers, and 64 MB texture memory. Mean system lag 110 ms. In-house software.
Visual display:		Virtual Research V8 HMD, with FOV 60° diagonal at 100% stereo overlap, 640 × 480 tri-color pixel resolution per eye. Update rate generally 20–30 Hz.
Audio display:		Real radio placed in location of virtual radio and used to give instructions to participants. A hand colliding with a virtual object caused a sound (different sounds for right and left hand; such a collision also changed block color to red) in the unaugmented virtual maze condition only.
Haptic display:		Solid objects made of styrofoam and cardboard used to define maze path.
Tracking:		Head tracking using University of North Carolina (UNC) Tech Hi-Ball, allowing movement in 4 × 10 m area. Hand and knee tracking using Polhemus FastTraks.
Navigation:		Actual walking.
Object manipulation:		Joystick with push buttons.
Virtual world:		Room furnished with rectangular colored objects forming a single-path maze, where path consisted of 11 turns. Patterned textures used on floor, walls, and ceiling.
Training:		None.
Experimental task:		Complete 3 clockwise laps through the environment, touching all objects, while trying to get a sense of the layout. Then, while blindfolded, complete 1 lap in equivalent real-world maze, this time without touching objects.
Participants:		33 undergraduate computer science students; 17 males; age range 19 to 23.
Study design:		Between-subjects.
Presence measures:		Witmer-Singer PQ.
Person-related meas.:		Guilford-Zimmerman Spatial Orientation Test, gender.
Performance measures:		*Cognitive sketch maps, height estimation of 4 objects, estimated distance between two objects. In RE: time to complete lap, number of object collisions, number of wrong turns*.
Finding:	(1)	Haptic cues had no significant relationship with presence.
	(2)	Gender had no significant association with presence.
	(3)	Spatial orientation score had no significant association with presence.
	(4)	*Practice in mixed-reality maze was associated with a significant improvement on completion time, number of collisions, distance estimation accuracy, and number of attempted wrong turns.*
	(5)	*Haptic cues had no significant relationship with sketch map accuracy and height estimation accuracy.*

[Jang 2002] Jang, D. P., Kim, I. Y., Nam, S. W., Wiederhold, B. R., Wiederhold, M. D., and Kim, S. I. (2002). Analysis of physiological response to two virtual environments: Driving and flying simulation. *CyberPsychology, 5* (1), 11–18.

Factors:	Virtual world type (simple/flying, complex/driving).
Computing platform:	Driving simulator used Pentium 600 PC with 3D accelerator graphics card. Physiological measurements captured using an I-330 C-2 computerized biofeedback system from J&J Engineering.
Visual display:	Interactive Imaging Systems VFX3D HMD.
Haptic display:	Subwoofer in flight seat used for flying virtual world, and vibration chair used for driving virtual world. Both driven using sound from computer.

Tracking: Head tracking used for each virtual world.
Navigation: Steering wheel used for driving virtual world only.
Virtual world: Flying virtual world developed for treatment of fear of flying. Participant placed in window seat in the passenger cabin of a commercial aircraft and experiences different parts of a flight. Driving virtual world consisted of an urban street, secluded road, and a long tunnel with traffic jam; traffic lights, traffic sounds copying those in the real world.
Training: For flying virtual world, look around plane to get oriented. For driving simulator, instruction in use of controls.
Experimental task: Using flying virtual world, experience sitting in plane, taxiing, taking off, flying in good weather, flying in bad weather, and landing. Using driving virtual world, follow traffic through different road areas while an operator controls the level of traffic. 15 min.
Study design: Within-subject.
Participants: 11 nonphobic participants over 18 years old.
Presence measures: %Δskin resistance, %Δheart rate, %Δskin temperature. 12-item Presence and Realism Questionnaire.
Person-related meas.: Tellegen Absorption Scale (TAS), Dissociative Experience Scale (DES), *age*.
Task-related measures: Kennedy SSQ.
Findings:
(1) Type of virtual world had no significant relationship with any presence measure.
(2) There was no significant correlation between either TAS or DES scores and any measure of presence.
(3) Type of virtual world had no relationship with SSQ scores.
(4) Age had a significant positive correlation with SSQ scores only after experiencing the driving task.

[Jeandrain 2004] Jeandrain, A.-C. (2004). Why and how do the telepresence dimensions influence persuasive outcomes? *Proceedings of the 7th Annual International Workshop on Presence*, Valencia, Spain, October, 73–79.

Factors: Social presence manipulation (high social presence, low social presence).
Visual display: Desktop monitor.
Object manipulation: None.
Virtual world: Two virtual computer stores, one with 69 number of detailed media portrayals that are plausible or “true to life,” other with 18 such portrayals. Stores had two floors, the first showing the stimulus product and the second showing video games. Focal product was a notebook computer. Major collateral products were game-oriented products.
Training: Navigation training in a virtual labyrinth.
Experimental task: Exploration with no time limit.
Participants: 63 undergraduates recruited from communication courses.
Presence measures: 34-item ITC-SOPI.
Person-related meas.: Internet usage.
Task-related measures: 5-item global attitude toward brand scale, 6-item attitude toward purchasing brand scale, 12-item global attitude toward virtual store scale, *2-item scale on social realism*, *product realism scale*.
Findings:
(1) Participants gave significantly higher ITC-SOPI Physical Space, Engagement, and Naturalness subscale scores for the high social presence condition.
(2) Brand attitude confidence had a significant negative association with ITC-SOPI Engagement.
(3) Store attitude confidence had a significant positive association with ITC-SOPI Physical scale.
(4) Global brand attitude and attitude toward purchasing the brand had a significant positive association with ITC-SOPI Naturalness.

(5) Significantly higher social realism and product realism ratings were given for the high social presence condition.

[Johnson 1995] Johnson, D. M., and Wightman, D. C. (November 1995). *Using virtual environments for terrain familiarization: Validation* (ARI Technical Report ARI-RR-1686). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors: Detail level (Hanchey Army Heliport (HAH), portion of Arizona)).
Computing platform: Simulator Training Research Advanced Testbed for Aviation (STRATA).
Visual display: Stereoscopic, fiber-optic helmet-mounted display with FOV 127º H x 66º V, resolution 5 arcminutes for background and 1.5 arcminutes for high-resolution insets in the center of the visual field, luminance > 35 fL (foot-lamberts) contrast ratio 50:1. Helmet individually fitted and optically aligned for each participant. Update rate 60 Hz. Participant seated in an AH-64A Apache helicopter pilot cockpit simulator with all flight instruments/controls/motion displays switched off or covered by a black blanket. Black curtain surrounded cockpit area.
Audio display: Intercom system.
Tracking: Infrared (IR) head tracking system.
Navigation: Joysticks attached to right and left arms of seat to control up/down or left/right movement, with button to reposition participant to a preset VE location.
Object manipulation: None.
Virtual world:
(1) HAH at Fort Rucker (Alabama). "T-shaped" area with dimensions approximately 0.5×0.7 mi, including all features relevant to flight training missions, with structure colors matched from photos or videotape, signs and logos texture mapped onto buildings. Area included 19 helipads with parking ramps, taxi lanes, and overrun areas; 30 (semi) permanent buildings, control tower, beacon tower, antenna pole, 3 windsocks, 4 fuel tanks; and miscellaneous objects such as fire trucks, water tank, satellite receiver dish. One of each of four types of helicopter cycled continuously through their respective traffic patterns.
(2) Portion of Arizona taken from Simulator Training Research Advanced Testbed for Aviation (STRATA) Arizona database. Approximately 10×10 mi. Area centered east of Phoenix and included part of Mesa. Contained urban, residential, and desert terrain; with appropriate types and densities of buildings, businesses, churches, houses, towers, playgrounds cars, roads, parking lots, signs, stream, and vegetation; no moving models.

Both virtual worlds had a large, red 3D cursor in lower center FOV pointing to magnetic north. Participants were represented in each virtual world by a black 2.5×3 ft virtual carpet they could see underneath their seat and feet when they looked down.
Training: Familiarization with cockpit, helmet-mounted display, and 3 min of practice using joysticks.
Experimental task: Self-guided exploration of either HAH or Arizona VE. Three 30-min sessions.
Participants: 12 soldiers from aviation units at Fort Rucker; 10 males; age range 23 to 20; mean age 28.3 years. None had previously visited the HAH.
Presence measures: 32-item Witmer-Singer PQ Version 2.0.
Findings: (1) Level of detail had no significant relationship with presence.

[JTAP 2000] JISC Technology Applications Programme. (February 2000). *JTAP Project 305: Human factors aspects of virtual design environments in education project*. Loughborough University, UK.

Computing platform: Division Inc. ProVision100 system, with dVS Version 3.1.2.
Visual display: Division Inc. HMD.
Tracking: Polhemus FASTRAK for head tracking.

Navigation:		Using Division Inc. 3D mouse.
Object manipulation:		Using Division Inc. 3D mouse.
Virtual world:		Tool box.
Experimental task:		Perform a series of create, link, and animation operations according to a predefined task list to develop virtual scenes.
Participants:		18 participants.
Presence measures:		10-item presence section on VRUSE questionnaire, also includes 11-items related to simulation fidelity.
Findings:	(1)	Quality of simulation had a significant positive correlation with the sense of immersion, the sense of "being present," and overall feeling of being present in the VE.
	(2)	Fidelity of the VE had a significant positive correlation with sense of being immersed.
	(3)	A belief that the quality of the simulation improved performance had a significant positive correlation with the sense of presence and the overall feeling of "being present" in the VE.
	(4)	Accuracy of simulation had a significant positive correlation with both the sense of immersion and the sense of presence.

[Juan 2006] Juan, M. C., Baños, R., Botella, C., Pérez, D. Alcañiz, M., and Monserrat, C. (2006). An augmented reality system for the treatment of acrophobia: The sense of presence using immersive photography. *Presence, 15* (4), 393–402.

Factors:		Environment type (real, immersive photography augmented reality).
Computing platform:		AR-acrophobia system running on standard PC. Immersive photographs taken using digital color Coolpix 4500 Nikon Camera and FC-E8 Fisheye converter. Real world captured using a Dragonfly camera attached to HMD.
Visual display:		5DT HMD with 800 × 600 resolution, 40º FOV for participant, desktop monitor for therapist.
Tracking:		Xsens Motion Technologies MTx tracker for head tracking.
Virtual world:		The space was a terrace of the Applied Computer Science Superior Technical School building from which a staircase could be seen.
Experimental task:		First, a narrative was given (role of security guard who must watch for burglars). 7 min.
Participants:		41 participants; 28 males. Students, scholars, or university employees. Participants had no fear of heights.
Study design:		Within-subjects.
Presence measures:		6-item SUS Questionnaire.
Findings:	(1)	Participants' presence scores were significantly lower on each SUS item and for SUS Total scores for the immersive photography environment.

[Jurnet 2005] Jurnet, I. A., Beciu, C. C., and Maldonado, J. G. (2005). individual differences in the sense of presence. *Proceedings of the 8th International Workshop on Presence*, London, UK, September, 133–142.

Factors:	Personal test anxiety (high, low).
Computing platform:	Pentium IV with Hercules 3D Prophet 9700 PRO graphics card. Windows 2000. Virtual worlds developed using 3D Studio Max 6, Poser 4, Virtools Dev 2.5.
Visual display:	I-Visor DH-4400VP HMD with 800 × 600 resolution, 31º diagonal FOV.
Tracking:	InterSense 3 DOF Tracker for head tracking.
Virtual world:	Chronological series of virtual scenarios. Situations and elements comprising the scenario based on survey. (1) House. Student's home representing day before and morning of the examination; the corridor and lecture-hall where examination takes place. Flat with bedroom, kitchen, and hall (and clocks throughout), where participant can

conduct typical activities such as opening windows, lying on bed, eating and drinking. For day before, text book and notes serve as reminder examination is next day. For day of examination, alarm clock sounds at 7:30 a.m., and student goes through normal start of day activities.

(2) Metro. Part of Barcelona underground system. Scenario includes waiting for train, other students talking, then a journey lasting 3 stops.

(3) University. Student waits in a hallway outside the lecture room were examination is to take place. Surrounded by students talking about the examination-related subjects. After 5 min, lecturer arrives with examinations and tells students they can go in. Student is seated and waits until examination handed out. After lecturer's instructions, examination appears in front of student with 25 multiple choice questions to answer.

Training: Learn navigation in a virtual room composed of elements such as tables, chairs, sofa, and switches.

Experimental task: Work through scenarios, answering "examination" questions in final scenario.

Participants: 26 participants; 16 with high test anxiety, 10 with low; 4 males; mean age 22.85 years. Participants selected from an initial pool of 306 university students; selected based scores on Test Anxiety Inventory (TAI) in or above 75th percentile and at or below 25th percentile.

Presence measures: 14-item IPQ completed after House, Metro, University scenarios.

Person-related meas.: TAI, Eysenck Personality Questionnaire (EPQ) Short Revised version with Extraversion, Neuroticism, Psychoticism, Social Conformity or Lie subscales, Verbalizer-Visualizer Questionnaire (VVQ), spatial ability based on Solid Figures Rotation, computer experience questionnaire.

Findings:
(1) EPQ Extraversion subscale had a significant negative correlation with overall IPQ scores and those from House and Metro scenarios.
(2) Sold Figures Rotation had a significant positive correlation with overall IPQ scores and those from House scenario.
(3) VVQ and computer experience had no significant association with IPQ scores.
(4) TAI had a significant positive correlation with overall IPQ scores and those from Metro scenario.

[Kim 2004] Kim, J., Kim, H., Muniyandi, M., Srinivasan, M. A., Jordan, J., Mortensen, J., Oliveira, M., and Slater, M. (2004). Transatlantic touch: A study of haptic collaboration over long distance. *Presence, 13* (3), 328–337. See also Jordan, J., Mortensen, J., Oliveira, M., and Slater, M. (2002). *Collaboration in a mediated haptic environment*. Paper presented at the 5th Annual International Workshop on Presence, Porto, Portugal, October.

Factors: Haptic force feedback (present, absent), pointer directional information (present, absent).

Computing platform: Dual 0.9-GHz PC, 256 MB RAM, with NVIDIA GeForce2-based graphics card at one site, running Microsoft Windows NT. 1-GHz PC, 512 MB RAM, with NVIDIA GeForce2-based graphics card at other site, running Microsoft Windows 2000. Sites connected with Internet2 network with round-trip time of 90 ms. SensAble Technologies GHOST Software Development Kit and OpenGL development software.

Visual display: 19-in. monitor at each site.

Object manipulation: SensAble Technologies PHANTOM force-feedback device at each site, with update rate 1000 Hz, 6 DOF motion, 3 DOF force feedback.

Virtual world: Room containing a cube and 2 probes. Walls of room constrain cube movement. Gravity set of 9.8 m/s^2 and high dynamic and static coefficients of friction between cube and walls and between cube and pointers.

Training: Practice lifting block for a few minutes.

Experimental task: Approach the box and cooperate (with an experimenter) to lift it by exerting pressure upwards and toward one side of the box only. Then, keep the box off the ground as long as possible. 2 min allowed.
Participants: 20 participants.
Study design: Between-groups.
Presence measures: 7-item co-presence questionnaire.
Person-related meas.: Age.
Findings:
(1) Use of haptic force feedback was associated with significantly higher co-presence scores.
(2) Use of directional information was associated with reduction in co-presence scores.
(3) Age had a significant association with co-presence, with less co-presence reported for older ages.

[Kizony 2004] Kizony, R., Katz, N., and Weiss, P. L. (2004). Virtual reality based intervention in rehabilitation: Relationship between motor and cognitive abilities and performance within virtual environments for patients with stroke. *Proceedings of the 5th International Conference on Disability, Virtual Reality and Associated Technologies*, Oxford, UK, September, 19–26.

Computing platform: VividGroup (now GestureTek) GX-video capture system.
Virtual world: GestureTek's GX100 Birds & Balls, Soccer GX, and Snow Boarding motion-based games.
Experimental task: Play each game for 3 to 4 min.
Participants: 13 stroke patients; 9 males; mean age 66.3 years. 7 patients had a left hemispheric stroke, 6 had a right hemispheric stroke. Time on onset stroke and study participation ranged from 5 weeks to 11 months. Inclusion criteria: independence in activities of daily living prior to stroke, ability to understand instructions and sign informed consent, ability to move affected upper extremity independently or with aid on nonaffected arm.
Presence measures: 8-item Scenario Feedback Questionnaire (SFQ), including 6 items addressing presence (based on Witmer-Singer PQ).
Person-related meas.: Motor and sensory abilities: *Fugl-Meyer Motor Assessment*, *Ashworth scale*, *Thumb test*, *Functional Reach Test*. Cognitive abilities: *Star cancellation test, Mesulam symbol cancellation test*, *Contextual Memory Test*, *Lowenstein Occupational Therapy Cognitive Assessment*, *Behavioral Assessment of Dysexecutive Syndrome*. Evaluated ~ 1 week after VR session.
Performance measures: Game scores.
Findings:
(1) Performance in Soccer had a significant positive correlation with presence (p = 0.05).
(2) Patients achieved significantly higher game scores for Snowboard.
(3) Performance in Soccer had a significant positive correlation with level of enjoyment.
(4) Significant correlations were found between several of the cognitive tests and game scores.
(5) Perceived exertion was significantly higher for Soccer than for Birds & Balls.
(6) Perceived difficulty was significantly higher for Soccer than for Snowboard.

[Klimmt 2005] Klimmt, C., Hartmann, T., Gysbers, A., and Vorderer, P. (2005). The value of reaction-time measures in presence research. *Proceedings of the 8th International Workshop on Presence*, London, UK, September, 293–298.

Factors: FOV (61º, 20º), Secondary Task Reaction Time (used, not used).
Visual display: 2 desktop monitors, 1 for virtual world and 1 for STRT.
Navigation: Standard mouse/keyboard.
Object manipulation: Using mouse/keyboard.

Virtual world:		Multi-floor, multi-room museum with a large number of exhibits such as paintings, instruments, historical musical notes, and documents. Contained information desks and tables, loudspeakers, benches, and so forth. Supported simple interactions with different exhibition objects. Stairs between floors. Developed using WorldUp.
Experimental task:		Explore virtual museum for 7 min.
Participants:		Overall study with hypertext, film, and VE conditions: 168 participants from several universities. VE element: 47 participants.
Study design:		Mixed.
Presence measures:		MEC-SPQ, STRT using three types of probes (1) visual: red square appearing on second monitor, (2) auditory: alarm sound (~ 70 dB) produced by a typical siren, (3) combined visual/auditory: red square and alarm sound. Participant had to react by pressing "Spacebar" button on a computer keyboard unrelated to navigation and virtual object interaction.
Findings:	(1)	FOV had no significant relationship with either presence measure.
	(2)	STRT audio/visual probe had a significant positive correlation with MEC-SPQ Involvement.

[Knerr 1994 (1)] Knerr, B. W., Goldberg, S. L., Lampton, D. R., Witmer, B. G. Bliss, J. P., Moshell, J. M., and Blau, B. S. (1994). Research in the use of virtual environment technology to train dismounted soldiers. *Journal of Interactive Instruction Development, 6* (4), Spring 1994, 9–20.

Factors:		Navigation (joystick, spaceball).
Computing platform:		Two 486, 50-MHz PCs with Intel DVI display boards. Sense8 Corporation WorldToolkit.
Visual display:		Virtual Research Flight Helmet.
Tracking:		Polhemus Isotrack for head tracking.
Navigation:		Gravis joystick or Spaceball Tech Spaceball.
Virtual world:		Virtual Environment Performance Assessment Battery (VEPAB) world.
Experimental task:		Complete 20 tasks from VEPAB battery, ranging from vision to reaction time tests.
Participants:		24 participants, primarily college students.
Presence measures:		Witmer-Singer PQ.
Person-related meas.:		Witmer-Singer ITQ.
Task-related measures:		Kennedy SSQ.
Performance measures:		*Completion time for locomotion task*, *object manipulation task*, *tasking tasks*.
Findings:	(1)	ITQ score had no significant correlation with PQ score.
	(2)	SSQ Total score had a significant negative correlation with PQ score.
	(3)	*Type navigation had a significant relationship with completion time for locomotion and object manipulation tasks, with quicker time found for joystick but had no significant relationship with completion time for tracking tasks.*

[Krijn 2004] Krijn, M., Emmelkamp, P. M. G., Biemond, R., de Wilde de Ligny, C., Schuemie, M. J., and van der Mast, C. A. P. G. (2004). Treatment of acrophobia in virtual reality: The role of immersion and presence. *Behavior Research and Therapy, 42,* 229–239.

Factors:	Visual display (Cave, HMD), therapy (Virtual Reality Exposure Therapy (VRET), wait list)).
Computing platform:	For HMD condition, 450-MHz Pentium II computer with 2 Intergraph Intense 3D Pro 2200 graphic cards, 16 MB texture memory. For Cave condition, SGI Onyx2 Reality Monster with 8 processors, 4 graphics pipes. Sense 8 WorldUp to generate virtual worlds with image generation at 15–20 fps.
Visual display:	For HMD condition, Cybermind Visette Pro in stereographic mode, with 70.5º diagonal FOV. For Cave condition, 4-sided Cave with CrystalEyes shutter glasses.
Tracking:	Ascension Technology's Flock of Birds for head tracking in each condition.
Navigation:	Patients could walk freely in 1 m^2.

Virtual world:	For virtual worlds: a shopping mall with 4 floors, a fire escape with 6 floors in open space, a roof garden on a building, and a building site with 8 floors.
Experimental task:	Treatment consisted of three 1.5-hr sessions devoted only to VRET. Patients started on the ground floor of the first virtual world and were encouraged to take the next step (e.g., take hand of railing or move up a floor); move up after habituation or a relatively low anxiety Subjective Unit of Discomfort Scale (SUDS). Only exposure therapy and encouragement were used; no cognitive interventions or relaxation were given.
Participants:	22 (14 Cave, 10 HMD) patients meeting current Diagnostic and Statistical Manual of Mental Disorders 4th Edition (DSM-IV) criteria for specific phobia, naturalistic type. Acrophobia was the main complaint. Exclusion criteria: fulfilling criteria for panic disorder, use of tranquilizers, use of glasses stronger than –3.5. For 30 participants (before final dropouts in waiting period), 18 males; mean age 50.6 years; mean duration of acrophobia 33.5 years.
Study design:	Between-subjects.
Presence measures:	IPQ, used halfway through and at end of each session.
Person-related meas.:	State Trait Anxiety Inventory, Acrophobia Questionnaire (AQ), *Attitude Towards Height Questionnaire (ATHQ)*, *Symptom Checklist-90 (SCL-90) scale for general psychopathology*.
Task-related measures:	*Anxiety SUDS rating taken halfway and at the end of each session*, *Behavior Avoidance Test (BAT) taken before and after treatment (or a waiting period)*.
Findings: (1)	Patients who used the Cave display reported significantly more presence.
(2)	State anxiety had no significant association with presence scores in any session.
(3)	For (10) dropouts who did not complete therapy because they did not experience any anxiety, experience of presence was significantly lower during the first half of the session compared with the scores of those who completed the treatment. (Pretest AQ-Avoidance scores were significantly higher, and SCL-90 scores were significantly lower.)
(4)	*Based on the AQ-Anxiety, AQ-Avoidance, ATHQ, and BAT scores, VRET was significantly more effective than no treatment (waiting list patients). Gains made remained stable after 6 months.*
(5)	*Type of visual display had no significant association with effectiveness.*

[Laarni 2005] Laarni, J., Ravaja, N., and Saari, T. (2005). Presence experience in mobile gaming. *Proceedings of DiGRA 2005 Conference: Changing Views – Worlds in Play*, Vancouver, British Columbia, Canada, June, 6pp.

Factors:	Device type (PC, Personal Digital Assistant (PDA)).
Computing platform:	Dell Precision 350 computer with Panasonic Liquid Crystal Display (LCD) Projector PT-LC75E. Hand-held Compaq iPAQ PDA.
Visual display:	Large screen: 1.3 × 1.7 m or 8 × 6 cm.
Tracking:	None.
Navigation:	PC keyboard or pad.
Virtual world:	Colin McRae Rally or V-Rally game.
Training:	Practice with game for 5 min.
Experimental task:	Play rally game for ~ 5 min, restarting as necessary.
Participants:	50 participants; 17 males; age range 19 to 39; mean age 27 years.
Study design:	Between-subjects.
Presence measures:	MEC-SPQ.
Person-related meas.:	Witmer-Singer ITQ.
Findings: (1)	Participants using the PDA reported significantly less presence on MEC-SPQ Spatial Situation Model, Self Location, and Possible Actions subscales.
(2)	Device type had a significant interaction with ITQ Focus subscale for predicting MEC-SPQ Suspension of Disbelief scores. Those in the PC condition with high

Focus scores reported more suspension of disbelief. In the PDA condition, those with low Focus scores reported more suspension.

(3) Device type had a significant interaction with ITQ Games subscale for predicting MEC-SPQ Attention Allocation scores. Those with low Games scores reported more engagement in the PDA condition. Those with high Games scores reported more attention in the PC condition.

[Laarni 2004] Laarni, J., Ravaja, N., Saari, T., and Hartmann, T. (2004). Personality-related differences in subjective presence. *Proceedings of the 7th Annual International Workshop on Presence*, Valencia, Spain, October, 88–95.

Factors:	Task (single-task, dual-task).
Computing platform:	Power Macintosh 7200/90 computer.
Visual display:	17-in. desktop monitor with 800 × 600 resolution.
Auditory display:	SP-628 multimedia speakers. In dual-task condition, distracting sounds provided through loudspeaker positioned behind participant.
Tracking:	None.
Navigation:	Using keyboard.
Object manipulation:	Using keyboard.
Virtual world:	*The Art of Singing* CD. Multimedia presentation where user tours around a virtual academy of song. Academy has 3 floors, each with several rooms in which different activities took place.
Experimental task:	Experience virtual academy. For dual-task condition, also asked to generate 3-digit random numbers whenever a defined signal occurred (5 different signals, such as alarm, train, school bell), 12 signals. 10-min test session.
Participants:	80 participants; 29 males; age range 18 to 39; mean age 24 years.
Study design:	Between-subjects.
Presence measures:	MEC-SPQ, ITC-SOPI Sense of Physical Space, Engagement, and Naturalness subscales.
Person-related meas.:	Witmer-Singer ITQ, 20-item Behavioral Inhibition Scale/Behavioral Activation Scale (BIS/BAS) assessing reactivity to reward and punishment, 48-item EPQ Revised, short form, 19-item Zuckerman-Kuhlmann Personality Questionnaire-Impulsive Sensation Seeking (ZKPQ-ImpSS) scale, 11-item Self-Forgetful versus Self-Conscious Experiment Scale.

Findings:

(1) BAS score a significant negative association with Engagement. There was a significant interaction, such that participants with low BAS scores gave higher scores for Spatial Presence, Engagement, and Naturalness in the dual-task condition, while participants with high BAS scores gave higher Spatial Presence, Engagement, and Naturalness scores in the single-task condition.

(2) BIS scores had a significant interaction with condition, such that participants with high BAS scores gave lower ITC-SOPI Sense of Physical Space, Engagement, and Naturalness scores.

(3) EPQ Extraversion had a significant positive association with MEC-SPQ Spatial Presence and ITC-SOPI Sense of Physical Space.

(4) ImpSS Impulsivity had a significant positive association with Engagement.

(5) Self-forgetfulness had a significant positive association with MEC-SPQ Spatial Presence and ITC-SOPI Sense of Physical Space and Engagement.

(6) ITQ scores had a significant positive correlation with MEC-SPQ Spatial Presence and ITC-SOPI Sense of Physical Presence and Engagement.

[Ladeira 2005] Ladeira, I., Nunez, D., and Blake, E. (2005). The role of content preference on thematic priming in virtual presence. *Proceedings of the 8th International Workshop on Presence*, London, UK, September, 227–230.

Factors:	Priming (thematic priming, no priming).
Computing platform:	Desktop computer.
Visual display:	Desktop monitor. Images displayed with frame rate 25–30 fps.
Auditory display:	Headphones.
Tracking:	None.
Navigation:	Using standard mouse and/or keyboard.
Object manipulation:	None.
Virtual world:	Main virtual world presented a mountainous, outdoor environment. In the distance, a group of San people ("bushmen" in South Africa) can be seen sitting around an animated fire in a large cave. When participant walks over to the gathering, a San man from the group extends an invitation to join the rest in listening to a traditional San story selected from Bleek and Lloyd collection. Animations rotoscoped from an actress used to animate storyteller throughout narration. Cave modeled after Cederberg Mountains of the Western Cape, South Africa. Cave sides textured with San rock art related to the story. Various San objects, such as a hanging bag, placed in the cave. Reviewed by anthropologist to ensure as authentic as possible. Introductory virtual world presented a hip-hop artist with a radio, standing in front of a wall with graffiti including the word "San." Actions of a hip-hop musician were rotoscoped onto virtual actor. As participant walks forward, actor stops rapping and talks about San culture and storytelling tradition. He then directs participant to a door that opens to the main virtual world.
Training:	Practice navigating in training VE.
Experimental task:	Depending on condition, experience introductory virtual world and listen to hip-hop artist. In main virtual world, visit cave and listen to San storyteller.
Participants:	58 undergraduates from both Science and Humanities faculties; 35 males; mean age 20.42 years.
Study design:	Between-subjects.
Presence measures:	IPQ.
Person-related meas.:	6-item hip-hop interest questionnaire.
Findings: (1)	Use of priming was not significantly related to presence scores. There was an interaction with musical preference, such that participants who chose hip-hop as their favorite genre gave significantly higher presence scores.
(2)	Items measuring enjoyment and familiarity with hip-hop culture had no significant relationship with presence scores.

[Laframboise 2006] Laframboise, M-.R., Bouchard, S., Larouche, S., Robbilard, G., and Renaud, R. P. (2006). *The relation between anxiety and feeling of presence of flight phobic during VR immersion.* Poster presented at the 11th Annual Cyber Therapy Conference, Gatineau, Quebec, Canada, June.

Experimental task:	4 sessions of virtual exposure therapy, 60 min each (analyzed data from first 30 min).
Participants:	22 participants; 7 males. Diagnosed with flight phobia using Structured Clinical Interview for DSM-IV.
Presence measures:	Presence rating taken every 5 min.
Person-related meas.:	Anxiety rating taken every 5 min.
Findings: (1)	Presence increased significantly during the first session and did not change significantly between sessions.
(2)	Anxiety had a significant positive correlation with presence on some occasions.
(3)	*Anxiety decreased significantly with and between sessions.*

[Lampton 2001] Lampton, D. R., McDonald, D. P., Rodriguez, M. E., Cotton, J. E., Morris, C. S., Parsons, J., and Martin, G. (March 2001). *Instructional strategies for training teams in virtual environments* (ARI Technical Report 1110). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors:	Instructional strategy (demonstration, coaching, replay, no feedback).
Computing platform:	SGI Onyx RE2 with 8 processors/3 pipes, SGI Onyx RE2 with 4 processors/1 pipe, SGI Indigo High Impact, SGI Indy, Dell Pentium 90, Dell 486. Audio capture and playback using a Dell Optiplex 560 PC running Windows 95 with Sound Blaster AWE64.
Visual display:	Two Virtual Reality Corporation VR4 HMDs.
Audio display:	HMD headphones.
Tracking:	Two 6-tracker Ascension Technology's MotionStars for tracking body position, gaze, and locomotion.
Navigation:	Walking-in-place with participant standing within a circular barrier.
Object manipulation:	Palm grip of a Gravis Blackhawk joystick with thumb switch to cycle through an array of configurable hand-held items. Index finger trigger.
Virtual world:	10 rooms positioned along a hallway containing one 90° turn. Six floor plans, differing in directions in which the hallways branch and in the location of rooms. Seventh floor plan with a multistory structure. Gas canisters. Avatars depict a person in hazardous materials (HAZMAT) gear. Incorporate 45 DOF bends for realistic deflection of limbs and torso, raising and lowering of legs synchronized to participant locomotion, and articulating right arm synchronized to participant's arm movement. VE supports action-after critique system that provides a playback mechanism. Sound cues: gun shots, door opening/closing, collision sounds, and communications with team members.
Training:	Two virtual worlds for practice in walking in a VE and practice using the manual control device to select and use equipment. First virtual world consists of a large room and a connecting series of corridors. Second virtual world contains examples of various types of equipment, friendlies, enemies, and neutrals that can be encountered during missions. Participants practice using the pistol and necessary equipment. Each training mission took 8 min. The no-feedback group performed 2 trials in the second practice environment. The demonstration group watched replay of mission performed by the experienced team, followed by practice session. The replay group performed one practice mission followed by watching a replay of their performance. The coaching group was provided prompts or suggestions as team conducted 2 practice missions.
Experimental task:	Working in 2-person teams, search for canisters containing hazardous gas and, if necessary, deactivate canisters. Computer-generated enemy and innocent by-standers moved through hallways and rooms. Air supply limited to 8 min. Rules define order in which rooms are searched, team formation for room entry, actions on contact with enemy and innocent bystanders, assign areas of responsibility within a room, and how/what to report on the radio network.
Participants:	81 participants recruited from local colleges; approximately. 45% male; age range 17 to 52; mean age 21 years. Presence data collected from only 40 participants.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 2.0.
Person-related meas.:	29-item ITQ Version 2.0.
Performance measures:	*Task completion time*.
Findings: (1)	ITQ Total score had no significant correlation with PQ Total.
(2)	*Instructional strategy had no significant relationship with task completion time.*

[Larsson 2004] Larsson, P., Västfjäll, D., and Kleiner, M. (2004). Perception of self-motion and presence in auditory virtual environments. *Proceedings of the 7th Annual International Workshop on Presence*, Valencia, Spain, October, 252–258.

Factors:		Auralization quality (anechoic rendering, marketplace), number of concurrent sound sources (3, 1), input source sound (still, moving, artificial), turn velocity (20º, 40 º, 60º per sec).
Computing Platform:		Acoustic simulations rendered offline in CATT-Acoustic v8 using Walkthrough Convolver, with generic Head-Related Transfer Functions (HRTFs).
Visual display:		None.
Auditory display:		Beyerdynamic DT 990Pro circumaural headphones driven by a NAD Electronics amplifier.
Tracking:		None.
Navigation:		None.
Object manipulation:		None.
Virtual world:		Marketplace in Tübingen, Germany, with binaural simulations of a virtual listener standing in one place and rotating a certain number of laps. 3 still sound sources were a bus on idle, a small fountain, and a barking dog; 3 moving sound sources were footsteps, a bicycle, and a driving bus; 3 artificial sound sources were a stationary pink noise and differing pink noise bursts. Participant seated.
Training:		None.
Experimental task:		Verbally report direction of motion.
Participants:		26 participants; 13 males; mean age 24 years.
Study design:		Within-subjects for auralizarion quality and number of concurrent sound sources, between-subjects for input sound source.
Presence measures:		Magnitude estimation measure of presence, rating of realism.
Task-related measures:		*Rating of vection intensity and convincingness, count of vection experiences.*
Findings:	(1)	For single sounds analyzed separately from data for multiple sounds, only input source had a significant relationship with presence, with more presence reported using magnitude estimation for still sounds than for moving or artificial sounds. There was a significant interaction between sound sources, and auralization quality had a significant relationship with presence, with both the still and moving sound sources receiving higher ratings in the marketplace condition.
	(2)	For multiple sound sources, sound source had a significant relationship with presence reported using magnitude estimation, with greater presence reported for still and moving sources than for artificial sounds. Velocity had a significant effect, with more presence reported for 60º/s than for other velocities. Quality had a significant effect, with more presence reported for the marketplace environment than anechoic.
	(3)	For multiple sound sources, sound source had a significant relationship with realism, with artificial sounds rated less real than still and moving sounds. Quality had a significant effect, with the marketplace environment rated more realistic than anechoic.
	(4)	*For single sounds in the marketplace condition, type of sound source number had a significant relationship with the number of vection experiences, with more vection reported for still sources than either moving or artificial sources. For single sounds, turn velocity had no significant relationship with amount of vection.*
	(5)	*For single sounds, sound source only had a significant relationship with vection intensity, with more vection occurring for still sources. Sound source and quality had a significant relationship with ratings of vection convincingness, with more convincing vection reported for still sounds and marketplace quality.*

[Larsson 2001] Larsson, P., Västfjäll, D., and Kleiner, M. (2001). The actor-observer effect in virtual reality presentations. *CyberPsychology & Behavior, 4* (2), 239–246.

Factors:	Interaction (actor, observer).
Computing platform:	PIII-600 NT workstation with ELSA(R) Inc. Gloria XXL graphics board. Model created using CATT-Acoustic and transferred to EON Studio. Auditory scene rendered using Lake Technologies Aniscape software, CP4 hardware.
Visual display:	For actor condition, a Sony Glasstron HMD in stereoscopic mode. For observer condition, screen. All participants seated approximately 2 m from the projection screen.
Audio display:	For actor condition, Beyerdynamic DT 990 headphones. For observer condition, Sennheiser HD414 headphones.
Tracking:	For actor condition, Polhemus FASTRACK for head tracking.
Navigation:	Logitech Wingman regular joystick.
Object manipulation:	None.
Virtual world:	Model of Orgryte Nya Kyrka in Göteburg, Sweden. Some textures and two avatars. Auditory source was “Swanee River” performed by a female singer and visually represented as female avatar moving along a predetermined path in the church. Visual and auditory stimuli synchronized between female avatar and actor.
Training:	Instruction on use of joystick and HMD.
Experimental task:	For actor condition, count the number of windows in the church and find 4 different balls positioned in the church and then return to starting position. A sentence appears when move close to a ball, with the color of the text the same as the color of the next ball to be found. Task took about 10 min. Also requested to remember each piece of text.
Participants:	32 undergraduate or graduate students; 23 males; mean age 24.3 years.
Study design:	Between-subjects.
Presence measures:	4 presence questions (naturalness of interaction, extent of presence, extent of involvement, extent things did and happened naturally without much mental effort) part of SVUP questionnaire.
Task-related measures:	*Awareness of external/internal factors, sound quality, enjoyment, simulator sickness.*
Findings: (1)	Actors reported significantly higher presence scores.
(2)	*Actors reported significantly higher enjoyment scores.*
(3)	*Observers reported significantly higher external awareness and actors reported significantly more internal awareness.*
(4)	*Interaction had no significant effect ratings of sound quality.*
(5)	*Actors reported significantly more dizziness and headache symptoms.*

[Lawson 1998] Lawson, J. P. (September 1998). *Level of presence or engagement in one experience as a function of disengagement from a concurrent experience*. Master’s thesis, Naval Postgraduate School, Monterey, CA. See also Darken, R. P., Bernatovich, D., Lawson, J. P., and Peterson, B. (1999). Quantitative measures of presence in virtual environments: The roles of attention and spatial comprehension. *CyberPsychology & Behavior, 2* (4), 337–347.

Factors:	Visual display (Mini-Cave, HMD, flat screen), audio cues (present, absent), directions (attend to VE and videotape, attend to VE).
Computing platform:	SGI Onyx RE-2 workstation with four 194-MHz IP25 MIPS R10000 processors, InfiniteReality graphic board, 128 MB 20-way leaved main memory, 4 MB texture memory, 1-MB secondary cache, Iris Audi Processor Version A2. Coryhpheaus Software Designer’s Workbench, EasyTerrain and EasyScene, and Multigen software.

Visual display:	Virtual Research V8 HMD with resolution 640 × 3 × 480, FOV 60º, frame rate 18–24 fps; semi-circular mini-Cave using 3 Mitsubishi Model VS5071 40-in. rear projection screens with FOV 103º, frame rate 24 fps; 21-in. SGI Color monitor with resolution 1280 × 1024, FOV 33º, frame rate 30 fps. 20-in. monitor for viewing videotape. Participant seated with monitor for videotape display placed just off to the side in clear view.
Audio display:	Headphones, attached to HMD as appropriate.
Tracking:	Polhemus 3Space FASTRAK for head tracking.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Variation of H.G. Wells' *War of the Worlds* sited in SGI Performer Town.
Videotape:	Aardman Animations' short subject *Wallace and Gromit* videotape.
Training:	None.
Experimental task:	While on an automated car tour, observe the invasion of the town and various events. Videotape started a few minutes before the start of VE guided tour.
Participants:	70 participants; 52 males; mean age 37 years.
Study design:	Between-subjects.
Presence measures:	Engagement scores (VE quiz – RE quiz score), VE quiz score, RE quiz score, 32-item Witmer-Singer PQ Version 2.0.
Person-related meas.:	*Witmer-Singer ITQ*.
Findings: (1)	Visual display had no significant relationship with engagement score and VE quiz score, but user of the mini-Cave reported significantly higher RE quiz scores than HMD users.
(2)	Participants who attended to both the VE and real world achieved significantly lower engagement scores and RE quiz scores; interaction had no relationship with VE quiz scores.
(3)	Audio cues had no significant relationship with engagement scores but did have a significant positive relationship with VE and RE quiz scores.
(4)	VE quiz scores had a significant positive correlation with PQ scores.
(5)	*ITQ had no significant correlation with VE quiz scores.*

[Lee 2004a] Lee, S., Sukhatme, G. S., Kim, G. J., and Park, C.-M. (2004a). Effects of haptic feedback on telepresence and navigational performance. *Proceedings of the 14th International Conference on Artificial Telexistence,* Seoul, Korea, November–December. See also Lee, S., Sukhatme, G. S., Kim, G. J., and Park, C.-M. (June 2005). Haptic teleoperation of a mobile robot: A user study. *Presence: Teleoperators and Virtual Environments, 14* (3), 345–365.

Factors:	Force rendering (environmental and collision preventing, environmental, no force feedback).
Computing platform:	Activmedia Pioneer 2DX mobile robot equipped with 1 SICK LMS-200 laser scanner for front coverage, 8 Polaroid 600 series ultrasonic transducers for rear coverage, Sony EVID-30 camera.
Haptic display:	SensAble Technologies PHANTOM device.
Training:	In a virtual world equivalent to the real-world test condition, navigate a virtual robot represented as a cube with a top-center positioned virtual camera providing a 45 FOV, 640 × 480 resolution, front-facing laser scanner, rear-facing sonar array. Trained once for each force rendering method.
Experimental task:	Navigate the robot through an RE from a start to a goal position as safely as possible. 3 trials.
Participants:	12 participants; 10 males; age range 23 to 37.
Study design:	Within-subject.
Presence measures:	3-item presence questionnaire.
Task-related measures:	Perceived performance, *2-item force perception questionnaire*.
Performance meas.:	Number of collisions, time to complete.

Findings:	(1)	Environmental and collision-preventing and environmental-only conditions were associated with significantly higher presence scores than no force feedback.
	(2)	Perceived performance had a significant positive correlation with presence.
	(3)	Number of collisions had no significant correlation with presence.
	(4)	*Force rendering method had no significant relationship with time to complete.*
	(5)	*Environment and collision-preventing cues were associated with significantly fewer collisions.*
	(6)	*Perceived performance had a significant negative correlation with the number of collisions.*

[Lee 2004b (3)] Lee, S., Kim, G. J., Rizzo, A., and Park, H. (2004b). Formation of social presence: by form or content? *Proceedings of the 7th Annual International Workshop on Presence*, Valencia, Spain, October, 20–27.

Factors:		Visual detail (video, synthetic and high detail, synthetic and low detail), attention (with attentive task, without attentive task).
Visual display:		functional Magnetic Resonance Imaging (fMRI)-compatible HMD, monoscopic.
Audio display:		None.
Tracking:		None.
Navigation:		Passive navigation through fixed path.
Object manipulation:		None.
Virtual world:		Simple undersea world with rocks and fish. Geometric detail, inclusion of shadow, object motion, and texture resolution manipulated for high and low detail level.
Experimental task:		In attentive task condition, count number of pencils with special colors (red body and blue cap). Pencil body and cap could be red, green, blue, or white. 3 trial blocks of 30 sec each.
Participants:		36 participants, 12 of these experienced VE in the fMRI system.
Study design:		Between-subjects.
Presence measures:		10-item presence questionnaire, completed after each block of trials. Those in fMRI answered verbal so they could remain still.
Findings:	(1)	Participants gave significantly higher presence scores for video than for synthetic and high detail and for synthetic and high detail than for synthetic and low detail.
	(2)	Use of an attentive task had no significant relationship with presence.

[Lee 2003 (1)] Lee, K. M., and Naas, C. (2003). Designing social presence of social actors in human computer interaction. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Fort Lauderdale, USA, April, 289–296.

Factors:	Participant personality (extrovert, introvert), computer voice personality (extrovert, introvert).
Computing platform:	PC with Internet Explorer 4.0 browser.
Visual display:	Monitor.
Audio display:	Headphone.
Virtual world:	Web site for book buying that presents 5 books using a visual interface with a link to an audio file for book descriptions. Extrovert voice had speech rate of 216 words/min., 140-Hz fundamental frequency, 40-Hz pitch range. Introvert voice had speech rate of 184 words/min., volume level 15% of other, 84-Hz fundamental frequency, 16-Hz pitch range.
Experimental task:	Read instructions on Web site and listen to audio descriptions of books.
Participants:	72 undergraduate students; gender approximately balanced. Selected as having extreme extrovert or extreme introvert scores on a both Myers-Briggs and Wiggins personality tests.
Study design:	Between subjects.
Presence measures:	4-item social presence questionnaire.

Person-related meas.: Gender.
Task-related measures: *Extrovertedness/Introvertedness of voice questionnaire*.
Findings: (1) Participant personality had no significant relationship with social presence.
(2) Extrovert computer voice personality was associated with significantly higher social presence scores. Also, participant personality had a significant interaction effect on social presence, such that extroverts reported more social presence for the extrovert computer voice and introvert participants reported more presence for the introvert computer voice.
(3) Gender had no significant relationship with social presence.
(4) Extrovert computer voice personality was associated with significantly more extroverted ratings. Participant personality was not related to Extrovertedness/ Introvertedness.

[Lee 2003 (2)] Lee, K. M., and Naas, C. (2003). Designing social presence of social actors in human computer interaction. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Fort Lauderdale, USA, April, 289–296.

Factors: Participant personality (extrovert, introvert), computer voice personality (extrovert, introvert), item description (extrovert, introvert).
Computing platform: PC with Internet Explorer 4.0 browser.
Visual display: Monitor.
Audio display: Headphone.
Virtual world: Web site for online auction similar to e-bay providing names and pictures for 9 items. A link to an audio file provided item descriptions. Extrovert voice had speech rate of 216 words/minute, 140-Hz fundamental frequency, 40-Hz pitch range. Introvert voice had speech rate of 184 words/min., volume level 15% of other, 84-Hz fundamental frequency, 16-Hz pitch range.
Experimental task: Read instructions on Web site and listen to audio descriptions of items.
Participants: 80 undergraduate students; gender approximately balanced. Selected as having extreme extrovert or extreme introvert scores on a both Myers-Briggs and Wiggins personality tests.
Study design: Between-subjects.
Presence measures: 4-item social presence questionnaire.
Person-related meas.: Gender.
Task-related measures: *Extrovertedness/Introvertedness of voice questionnaire*.
Findings: (1) Extrovert computer voice personality was associated with significantly higher social presence. Participant personality had a significant interaction, such that extroverts reported more social presence for the extrovert computer voice and introvert participants reported more presence for the introvert computer voice. Also, a significant interaction with item description, such that the extrovert voice narrating extrovert text induced greater presence than when reading introvert text and vice versa.
(2) Gender had no significant relationship with social presence.
(3) Extrovert computer voice personality was associated with significantly more extroverted. Item description had a significant interaction, such that the extrovert description was rated as more extroverted.

[Lessiter 2001] Lessiter, J., and Freeman, J. (2001). Really hear? The effects of audio quality on presence. *Proceedings of the 4th Annual International Workshop on Presence,* Philadelphia, USA, May.

Factors: Audio mix (5 channels and bass, stereo, mono).
Visual display: 100-Hz Phillips 28-in. color TV, with viewing distance to render 29º visual angle display.

Audio display:		Left and right speakers, or 5 speakers surrounding participant and bass speaker behind seat.
Tracking:		None.
Audio sequences:		Sound mixes reflecting a moving car, with recordings of engine effects, gear noise, noise of stones hitting base of car as car drove over dips in the road, and noises of bumps while driving over dips.
Visual sequence:		Rally car sequence.
Experimental task:		Listen to audio while viewing video.
Participants:		18 students and college staff; 9 males; age range 20 to 57; mean age 30.8 years.
Study design:		Within-subjects.
Presence measures:		UTC-SOPI, 6-item SUS Questionnaire.
Task-related measures:		*Audio Experience Questionnaire (AEQ), identification of favorite audio mix*.
Findings:	(1)	Use of 5 channels and bass was associated with significantly higher ITC-SOPI Engagement scores than stereo or mono audio.
	(2)	Use of 5 channels and bass was associated with significantly higher SUS scores than stereo or mono audio.
	(3)	*Audio mix had a significant relationship with AEQ scores, with a better experience reported for the 5:1 mix for spaciousness/surrounding, loudness, discomfort associated with loudness, enjoyment, and overall rating items.*
	(4)	*5:1 mix was selected as favorite much more frequently than other mixes.*

[Lin 2004] Lin, J. J. W., Abi-Rached, H., and Lahav, M. (2004). Virtual guiding avatar: An effective procedures to reduce simulator sickness in virtual environments. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Vienna, Austria, April, 719–726.

Factors:		Motion predictor avatar (non-earth-fixed with turn cues, earth-fixed with turn cues, earth-fixed without turn cues, no prediction).
Computing platform:		Real Drive driving simulator including a full-size Saturn car, three 800 × 600 pixel Sony Superdata Multiscan VPH1252Q projectors, and motion platform.
Visual display:		Panoramic three 230 × 175 cm screen display with horizontal FOV (HFOV) 220º, viewed using CrystalEyes stereo glasses.
Navigation:		None.
Object manipulation:		None.
Virtual world:		University of Illinois Crayolaland cartoon world with a cabin, pond, flowerbeds, and a forest. A Virtual Guiding Avatar (VGA) in the form of an abstract airplane hovered centrally, facing the forward direction, predicting coming motion.
Training:		2-min practice trial viewed on monitor.
Experimental task:		In car, take 120-sec guided drive through Crayolaland on a quasi-circular trajectory that included left and right turns and forward and rearward translations. 4 trials with different starting points.
Participants:		10 Human Interface Technology Lab personnel; 5 males; age range 20 to 31.
Study design:		Within-subjects.
Presence measures:		9-item Engagement, Enjoyment, and Immersion (E^2I) scale with 4 factors (sensory, distraction, realism, control); includes 1-item structure of memory test score and 5-item enjoyment.
Task-related measures:		*Kennedy SSQ, perceived sharpness of turns, ability to predict turns*.
Performance measures:		(See Presence measures above.)
Findings:	(1)	Non-earth-fixed with turn cue and earth-fixed with turn cues were associated with significantly more presence than no prediction.
	(2)	*Non-earth-fixed with turn cue and earth-fixed with turn cues were associated with significantly fewer reports of SSQ symptoms.*
	(3)	*Earth-fixed with turn cues were associated with significantly more enjoyment than no prediction.*
	(4)	*Earth-fixed with turn cues associated with perception turns was less sharp.*
	(5)	*Motion predictor had no significant relationship with ability to predict turns.*

[Lin 2002] Lin, J. J.-W., Duh, H. B. L., Abi-Rached, H., Parker, D. E., and Furness III, T. A. (2002). Effects of field of view on presence, enjoyment, memory, and simulator sickness in a virtual environment. *Proceedings of IEEE Virtual Reality 2002,* Orlando, USA, March, 164–171.

Factors:	FOV (180º, 140º, 100º, 60º).
Computing platform:	Real Drive driving simulator including a full-size Saturn car, three 800 × 600 pixel Sony Superdata Multiscan VPH1252Q projectors, and motion platform.
Visual display:	Panoramic three 230 × 175 cm screen display with horizontal FOV 220º, viewed using CrystalEyes stereo glasses.
Navigation:	None.
Object manipulation:	None.
Virtual world:	University of Illinois Crayolaland cartoon world with a cabin, pond, flowerbeds, and a forest.
Training:	2-min practice trial viewed on monitor.
Experimental task:	In car, take 120-sec guided drive through Crayolaland on a quasi-circular trajectory that included left and right turns and forward and rearward translations. 4 trials with different starting points.
Participants:	10 Human Interface Technology Lab personnel; 5 males; age range 20 to 31.
Study design:	Within-subjects.
Presence measures:	9-item E^2I scale, 4 factors (sensory, distraction, realism, control); includes 1-item structure of memory test score and 5-item Enjoyment.
Task-related measures:	Kennedy SSQ.
Performance measures:	(See Presence measures [Lin 2004].)
Findings:	(1) FOV had a significant relationship with presence, with more presence reported for 180º than 100º and more presence reported for 100º FOV than for 60º.
	(2) Memory performance had a significant positive correlation with presence.
	(3) Enjoyment had no significant correlation with presence.
	(4) Presence and SSQ scores had a significant positive correlation.
	(5) Significantly more SSQ symptoms were reported for larger FOVs.
	(6) Enjoyment and SSQ scores had a significant negative correlation.

[Lok 2003] Lok, B., Naik, S., Whitton, M., and Brooks, Jr., F. P. (2003). Effects of handling real objects and avatar fidelity on cognitive task performance in virtual environments. *Proceedings of IEEE Virtual Reality 2003,* Los Angeles, USA, March, 125–132.

Factors:	Haptic cues (VE with real objects, VE with virtual objects), self-representation (generic with rubber gloves, visually faithful).
Computing platform:	SGI Reality Monster, using 1 rendering pipe at 20 fps for pure VE condition and 4 rendering pipes at 12–20 fps for hybrid condition. 4 NTSC resolution cameras for a 320 × 240 resolution reconstruction. Latency .03 sec, and 1-cm reconstruction error.
Visual display:	Virtual Research V8 HMD with 640 × 480 resolution per eye for VE. Television for real world.
Tracking:	UNC Hi-Ball tracker for head tracking, with Polhemus FASTRAK trackers for Pinch gloves.
Object manipulation:	Using Fakespace Pinch gloves in VE with virtual objects. Using yellow dish-washing gloves in hybrid VE.
Virtual world:	Virtual room included a lamp, a plant, and a painting and a virtual table registered with a real Styrofoam table. Participant standing in front of table on which blocks were placed. Self-representation in purely VE condition was neutral gray, generic. Self-representation in hybrid VE with accurate shape and generic appearance or visually faithful appearance.

Training: Practice task in real world using 6 block patterns (viewing blocks on television only) and 4 block patterns in VE.
Experimental task: Block arrangement task based on the Wechsler Adult Intelligent Scale, involving reasoning, problem solving, and spatial visualization. Involved small 4-block patterns and large 9-block patterns in 10 patterns (6 real timed, 4 VE timed).
Participants: 40 participants; 33 males. Taken or enrolled in a higher level mathematics course.
Study design: Between-subjects.
Presence measures: Expanded SUS Questionnaire.
Person-related meas.: Guilford-Zimmerman Aptitude Survey Part 5: Spatial orientation.
Task-related measures: *Kennedy SSQ, self-rating of task performance*.
Performance measures: *Time to correctly replicate given patterns*.
Findings:
(1) Haptic cues and self-representation had no significant relationship with presence.
(2) VE with real objects was associated with significantly improved performance.
(3) Visually faithful self-representation was associated with significantly improved task performance in the VE with virtual objects.
(4) Experimental conditions had a significant interaction for self-reports of performance, such that higher performance was reported for the hybrid VE with visually faithful self-representation than for the VE with virtual objects and generic self-representation.
(5) Experimental conditions had no significant relationship with SSQ scores.
(6) Spatial ability had no relationship with task performance.

[Mania 2004] Mania, K., and Robinson, A. (2004). The effect of quality of rendering on user lighting impressions and presence in virtual environments. *Proceedings of the 2004 ACM SIGGRAPH International Conference on Virtual-Reality Continuum and Its Applications in Industry,* Singapore, June, 200–205.

Factors: Rendering quality (high quality, mid quality, low quality).
Computing Platform: PC-based with graphics card. WorldUp with software that monitored participants' head movements. Average frame rate 12 fps.
Visual display: Kaiser ProView 30 stereoscopic HMD, with 30º diagonal FOV. IPD adjusted for each participant.
Tracking: Head tracking.
Virtual world: Academics office with objects, such as shelves, books, chairs, computer, and desk, and a single ceiling-mounted light source. Navigation restricted to 360º circle around the set viewpoint and 180º vertically.
Experimental task: Look around the virtual office for 45 sec.
Participants: 36 postgraduate students; 28 males.
Study design: Between subjects.
Presence measures: 3-item SUS questionnaire.
Task-related measures: Responses to lighting questionnaire. Kennedy SSQ.
Findings:
(1) Rendering quality had no significant relationship with presence.
(2) Responses to lighting had a significant positive correlation with presence.

[Mania 2003] Mania, K., Troscianko, T., Hawkes, R., and Chalmers, A. (2003). Fidelity metrics for virtual environment simulations based on spatial memory awareness tests. *Presence, 12* (3), 296–310.

Factors: Environment type (real, HMD mono head-tracked, HMD stereo head-tracked, monitor, HMD with mono mouse, desktop monitor).
Visual display: Kaiser ProView 30 HMD, 21-in. desktop monitor with mask; both providing 30º FOV, 640 × 480 resolution. IPD used to adjust HMD. Frame rate 14 fps.
Audio display: None.
Tracking: Head tracking.
Navigation: By rotating in a swivel chair.
Object manipulation: None.

Virtual world:	4 × 4 m room with a different landmark on each wall: a door and shelves, door and greenboard, whiteboard, small shelves at each end. Room also contained light fixtures, several tables, a swivel chair, and 21 primitive objects of approximately the same size. All objects were painted the same color. Photorealistic representation, with dimensions accurate to 1 cm and luminosity equivalent to real room. Texture mapping on doors and tables only.
Training:	None.
Experimental task:	Participants guided to the real or virtual room and seated in the swivel chair. 3 min to observe the room.
Participants:	21 undergraduate and M.Sc. students; 16 males. Frequent computer users.
Study design:	Between-subjects.
Presence measures:	6-item SUS Questionnaire.
Performance measures:	*Memory recall, confidence, and awareness state questionnaire completed after exposure and for 1-week retention test*.
Findings:	(1) Environment type had no significant relationship with presence.
	(2) Environment type had no significant relationship with memory recall or confidence.
	(3) Testing session had a significant association with memory recall and confidence, with lower scores reported for the retention test.

[Mania 2001a] Mania, K., and Chalmers, A. (2001a). The effects of levels of immersion on memory and presence in virtual environments: A reality centered approach. *CyberPsychology & Behavior, 4* (2), 247–263.

Factors:	Environment type (real, HMD, 3D desktop, audio-only).
Visual display:	Custom see-through, nonstereoscopic HMD with FOV approximately 30º H, resolution 1024 × 764. 21-in. monitor with FOV approximately 35º H, resolution 1152 × 864. Average update rate 45 fps. Rendered flat shaded.
Tracking:	None.
Navigation:	For visual conditions, used standard mouse to explore room from a steady viewpoint, approximately placed in center of room, with ability to move in a full circle.
Object manipulation:	None.
Virtual world:	Model of a university seminar room. Including slide show to present 12 “overhead” slides synchronized with audio taken from digital video recording from real condition.
Experimental task:	Attend a 15-min seminar on a nonscience topic. (Real condition included presentation of 12 slides on an overhead projector.)
Participants:	4 groups of 18 participants from a university campus and Hewlett Packard Labs, Bristol, UK; 14 males. Frequent computer users who had no prior knowledge of seminar subject matter.
Study design:	Between-subjects.
Presence measures:	6-item SUS presence questionnaire (slightly modified).
Person-related meas.:	Game playing experience.
Task-related measures:	Kennedy SSQ, *confidence ratings and memory awareness states (guess, familiar, remember*, *know) included with memory recall and spatial awareness questionnaire*.
Performance measures:	22-item memory recall, *spatial awareness questionnaire*.
Findings:	(1) Real condition was associated with significantly higher presence overall, and for all questions except 1 (images seen or heard compared with place visited), than HMD, 3D desktop, and audio-only conditions.
	(2) Game playing experience had no significant correlation with presence.
	(3) Total SSQ score had no significant correlation with presence in the HMD condition.
	(4) Memory recall had no significant correlation with presence.

(5) *Real condition was associated with significantly increased recall versus that in HMD and audio-only conditions.*
(6) *For memory recall, environment type had a significant relationship with confidence ratings, with increased confidence reported for the real condition versus desktop condition, and for the desktop condition versus HMD condition, and for audio-only conditions versus HMD condition.*
(7) *For memory recall, environment type had a significant relationship with memory awareness states, with more "guesses" made for HMD than either real or audio-only conditions only. Also a significantly higher probability that "guess" responses were correct for real, HMD, and audio-only conditions versus desktop condition.*
(8) *Visual stimulation had a significant positive association with memory recall performance with better performance for questions with answers written on slides and communicated aurally for the desktop versus audio-only condition.*
(9) *Environment type had no significant relationship with spatial awareness.*
(10) *For spatial awareness, environment type had no significant relationship with confidence ratings.*
(11) *For spatial awareness, environment type had a significant relationship with memory awareness states, with the probability of "remember" responses being correct higher for HMD compared to real conditions but not to desktop, and the probability of "familiar" responses being correct higher for the real compared to HMD conditions.*

[Mania 2001b] Mania, K. (2001b). Connections between lighting impressions and presence in real and virtual reality. *Proceedings of the 1st International Conference on Computer Graphics, Virtual Reality, Visualization, and Interaction*, Cape Town, South Africa, November, 119–123.

Factors:	Visual display (real, HMD stereo, HMD mono head-tracked, HMD mono mouse, desktop monitor).
Computing platform:	VE created using 3D Studio Max modeling suite and Lightscape radiosity software.
Visual display:	In real-world condition, goggles used to restrict FOV to same across all conditions. Resolution same across VE conditions. Photorealistic representation.
Tracking:	Head tracking for some conditions.
Navigation:	None.
Object manipulation:	None.
Virtual world:	4 × 4 m room. Viewpoint set in middle of room, with 360° horizontal rotation and 180° vertical rotation.
Experimental task:	Spatial task. 3-min exposure to virtual world.
Participants:	105 undergraduate and M.Sc. students.
Study design:	Between-subjects.
Presence measures:	6-item SUS Questionnaire.
Task-related measures:	Quality of lighting questionnaire.
Findings: (1)	Visual display had no significant relationship with presence.
(2)	Quality of lighting had a significant negative correlation with presence.
(3)	*Visual display had no significant relationship with ratings of quality of lighting.*

[Mania 2000] Mania, K., and Chalmers, A. (2000). A user-centered methodology for investigating presence and task performance. *Proceedings of the 3rd International Workshop on Presence,* Delft University of Technology, The Netherlands, March.

Factors:	Environment type (real, virtual with audio, audio only).
Computing platform:	PC with hardware accelerator. In-house Virtual Reality Modeling Language (VRML) and Java software.
Visual display:	21-in. monitor. Frame rate 40 fps.

Navigation: For visual conditions, used standard mouse to explore room from a steady viewpoint, approximately placed in center of room, with ability to move in a full circle, as well as emulating head movement.
Object manipulation: None.
Virtual world: Model of a university seminar room using static billboard with texture to display lecturer, and slide show to present 12 overhead slides. Slides synchronized with audio taken from digital video recording of real condition.
Experimental task: Attend a seminar in form of a 15-min lecture (included 12 slides shown on an overhead projector in real condition).
Participants: 3 groups of 18 participants.
Study design: Between-subjects.
Presence measures: 6-item SUS questionnaire.
Performance measures: 16-item knowledge acquisition.
Findings:
(1) Real condition was associated with significantly higher presence scores than those in virtual or audio only condition.
(2) Task performance had no significant correlation with presence.
(3) Real and audio-only conditions were associated with significantly improved performance over virtual with audio condition.
(4) Visual stimulation had a significant positive association with task performance, with better performance for questions with answers written on slides and mentioned by lecturer for the real and virtual conditions compared to audio-only.

[McLaughlin 2003] McLaughlin, M., Sukhatme, G., Peng, W., Zhu, W., and Parks, J. (2003). Performance and co-presence in heterogeneous haptic collaboration. *Proceedings of the 11th International Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (HAPTICS '03)*, Los Angeles, USA, March, 285–294.

Visual display: Desktop monitors.
Haptic display: PHANTOM, CyberGrasp glove.
Experimental task: PHANTOM user to communicate information to partner through a tactile "Morse Code" that maps the number of times a particular digit is touched onto letters of the alphabet. A keyboard showing this mapping is visible on his display. The participant using the CyberGrasp glove holds his hand stationary during transmission and then enters the letters received onto keyboard visible is his display. Nine 3- and 2-letter words to transmit.
Participants: 12 participants, working in pairs.
Presence measures: 8-item co-presence questionnaire.
Task-related measures: Mean force applied.
Performance measures: Task accuracy, *task completion time*.
Findings:
(1) Co-presence had no significant correlation with task accuracy.
(2) Co-presence had a significant negative correlation with mean force applied.
(3) Task completion time had a significant negative correlation with accuracy.
(4) Mean force applied had no significant correlation with accuracy.

[Meehan 2003] Meehan, M., Razzaque, S., Whitton, M. C., and Brooks, Jr., F. P. (2003). Effect of latency on presence in stressful virtual environments. *Proceedings of IEEE Virtual Reality 2003,* Los Angeles, USA, March, 141–148.

Factors: End-to-end latency (~ 50 ms, ~ 90 ms).
Computing Platform: 1.8-GHz Pentium IV PC with a dual NVIDIA GeForce Ti 4600 graphics card and Creative Labs Audigy sound card. Modified WildMagic software game engine. Additional PCs for data recording and viewing.
Visual Display: Virtual Research V8 HMD with 640 × 480 resolution for each eye, 60° diagonal FOV, refresh rate 60 Hz. IPD adjusted for each participant.

Audio display:	Sennheiser HD250 II sealed circumaural headphones replacing standard HMD headphones to provide spatialized background music coming from a virtual radio and instructions from a virtual wall-mounted speaker.
Haptic display:	Passive haptics using a real 1.5-in. wooden ledge, walls, and counters. Fan (and moving curtains) to simulate wind.
Tracking:	3rdTech HiBall 3000 tracker for head and hand position.
Physiological devices:	Thought Technologies ProComp+ Tethered Telemetry system, sampling skin conductance at 32 Hz and electrocardiogram (EKG) at 256 Hz. Essilor Digital Corneal Reflex Pupillometer (CRP). pupillometer for measuring a participant's IPD.
Virtual world:	Slater's virtual pit environment consisting of a training room and door leading to a 2-story tall pit room with a 2-ft ledge around a 20-ft chasm.
Training:	5 min used to familiarize participants with hardware devices and cable management. In practice VE room, responded to instructions to navigate around the room, and pick up and drop bean bags.
Experimental task:	Following recorded instructions, enter Pit Room, test a real 1.5-in. wooden ledge with their feet and drop two beanbags on target areas in the chasm.
Participants:	164 Special Interest Group on Computer Graphics (SIGGRAPH) 2002 conference participants; 132 males; mean age 35.
Study design:	Between-subjects.
Presence measures:	Shortened version of UCL Questionnaire with 1 item to rate amount of fear experienced and 5 presence items based on SUS Questionnaire with values of "5," "6," and "7" used for high presence rating, Δheart rate (data available for only 61 participants), Δskin conductance (data available for only 67 participants).
Task-related measures:	Kennedy SSQ, *self-reported fear*.
Findings:	(1) Latency had no significant relationship with presence and fear measured using the UCL questionnaire.
	(2) Lower latency was associated with a significant higher presence measured using Δheart rate (when the SSQ Nausea subscale was taken into account).
	(3) Latency had no significant relationship with Δskin conductance.
	(4) SSQ Nausea subscale had a significant positive correlation with both Δheart rate and Δskin conductance.
	(5) Reported fear had a significant positive correlation with SSQ Total score and Nausea, Ocular Discomfort, and Disorientation subscales.

[Meehan 2001 (1)] Meehan, M. (March 2001). *Physiological reactions as an objective measure of presence*. Doctoral dissertation, University of North Carolina, Chapel Hill. See also Meehan, M., Pugnetti, L., Riva, F., Barbieri, E., Mendozzi, L., and Carmagnani, E. (2000). Peripheral responses to a mental-stress inducing virtual environment experience. *Proceedings of the 3rd International Conference on Disability, Virtual Reality, and Associated Technologies,* Sardinia, Italy, September, 305–210.

Factors:	Multiple exposures (2 to 12).
Computing platform:	SGI Reality Monster, using 1 InfiniteReality2 graphics pipe. In-house software.
Visual display:	Virtual Research V8 HMD, with 640 × 480 tri-color pixel resolution per eye. Update rate generally 30 fps.
Haptic display:	Real 1.5-in. high plywood ledge registered with virtual ledge over chasm.
Tracking:	Large-area optical tracking system using UNC Tech Hi-Ball, allowing movement in 4 × 10 m area. Movement lag ~ 100 ms.
Navigation:	Actual walking.
Object manipulation:	Hand control with push buttons.
Virtual world:	Pit room entered from training room. In the pit room, a 20-ft chasm surrounded by a 2-ft walkway, with a ledge extending over the chasm. Area 18 × 32 ft. VE ranged from 10,000–20,000 polygons, with 41–50 MB texture mapping. Self-representation as virtual body.
Training:	Training room where users learn to navigate and pick up and move a virtual book. Approximately 2 min.

Experimental task:		Carry a virtual book into the pit room and place on a chair on the far side of the pit from the entrance. Typically took 40 sec.
Participants:		10 participants; 3 males; mean age 24.4 years. Three or fewer prior experiences of immersive VEs.
Study design:		Within-subjects.
Presence measures:		Δskin conductance level, Δskin temperature, UCL questionnaire. Observed behavioral measures: count of behaviors believed to be associated with moving about near a real 20-ft drop, such as slower motion, leaning against wall, testing edge with foot, and vocal exclamation.
Task-related measures:		Kennedy SSQ.
Findings:	(1)	Repeated exposures had a significant negative relationship with Δskin temperature and reported behavioral presence after the first exposure and on observed behavioral presence on subsequent days. It had a significant positive relationship with Δskin conductance. No significant relationship with other presence measures.
	(2)	Δskin conductance, Δskin temperature, and observed behavioral presence had no significant correlation with either reported presence or reported behavioral presence.

[Meehan 2001 (2)] Meehan, M. (March 2001). *Physiological reactions as an objective measure of presence*. Doctoral dissertation, University of North Carolina, Chapel Hill. See also Insko, B. E. (2001). *Passive haptics significantly enhances virtual environments*. Doctoral dissertation, University of North Carolina, Chapel Hill See also Meehan, M., Insko, B., Whitton, M., and Brooks, Jr., F. P. (2001). *Physiological measures of presence in virtual environments* (Technical Report TR01-009). Chapel Hill, NC: University of North Carolina, Department of Computer Science.

Factors:		Haptic cues (mixed reality wooden ledge, virtual ledge only).
Computing platform…		
Virtual world:		As in [Meehan 2001 (1)].
Training:		As in [Meehan 2001 (1)], but included viewing pit room from doorway.
Experimental task:		Carry a virtual book into the pit room and to the end of a wooden diving board. Count to 10 and look around. Then, carry book to a chair on the far side of the pit from the entrance. Pit surrounded by a narrow ledge. Typically took 90 sec.
Participants:		52 participants; 36 males; mean age 21.4. Three or fewer prior experiences of immersive VEs.
Study design:		Within-subjects.
Presence measures…		
Task-related measures:		As in [Meehan 2001 (1)], with Δheart rate added to Presence measures.
Findings:	(1)	Mixed reality wooden ledge was associated with significantly higher presence as assessed using Δheart rate, Δskin conductance, observed behavior, and reported behavioral presence. Haptic cues had no relationship with reported presence or Δskin temperature.
	(2)	Δheart rate, Δskin conductance, and Δskin temperature had no significant correlation with either reported presence or reported behavioral presence. Observed behavioral presence had no significant correlation with reported presence but had a significant positive correlation with reported behavioral presence.
	(3)	Repeated exposures had a significant negative relationship with reported presence and reported behavioral presence after the first exposure only. No significant effect for other presence measures.

[Meehan 2001 (3)] Meehan, M. (March 2001). *Physiological reactions as an objective measure of presence*. Doctoral dissertation, University of North Carolina, Chapel Hill. See also Meehan, M., Insko, B., Whitton, M., and Brooks, Jr., F. P. (2001). *Physiological measures of presence in virtual environments* (Technical Report TR01-009). Chapel Hill, NC: University of North Carolina, Department of Computer Science.

Factors:		Frame rate (30, 20, 15, 10 fps).
Computing platform…		
Training:		As in [Meehan 2001 (1)].
Experimental task:		Carry a virtual block into the pit room and drop it over a spot marked on floor of pit and then grab additional blocks floating in the air and drop those at other locations marked on the pit floor. Typically took 90 sec.
Participants:		33 participants; 25 males; mean age 22.3. Three or fewer prior experiences of immersive VEs.
Study design:		Within-subjects.
Presence measures…		
Task-related measures:		As in [Meehan 2001 (1)].
Findings:	(1)	Frame rate had a significant relationship with Δheart rate, Δskin conductance, Δskin temperature, reported behavioral presence only (part of UCL questionnaire), and observed behavioral presence, with more presence reported for 30 and 20 fps rates.
	(2)	Δheart rate, Δskin conductance, Δskin temperature and observed behavioral presence had no significant correlation with either reported presence or reported behavioral presence.
	(3)	Observed behavioral presence had no significant correlation with reported presence but had a significant positive correlation with reported behavioral presence.
	(4)	Repeated exposures had a significant negative relationship with Δskin conductance, Δskin temperature, and observed behavioral presence after first exposure only and on Δheart rate and reported behavioral presence over exposures on the same day. No significant relationship with reported presence.

[Michaud 2004] Michaud, M., Bouchard, S., Dumoulin, S., Zhong, X. W., and Renaud, P. (2004). Manipulating presence and its impact on anxiety. *Cyberpsychology & Behavior, 7* (3), 297–298.

Factors:		Presence manipulation (maximized presence, disrupted presence).
Computing platform:		IBM Pentium IV with ATI Technologies, Inc. graphics card.
Visual display:		Cy-Visor HMD. Covered with a dark cloth in maximized condition (participant in a dark and quiet room). Not covered in disrupted condition (participant in a lighted room where music played).
Tracking:		InterSense InterTrax tracker.
Virtual world:		15-floor building.
Experimental task:		Perform a feared task in two 10-min immersions on a virtual bridge: (1) select which floor to exit, take elevator to selected level, exit elevator and (2) walk on a scaffold crossing the street, hit a plank with the foot and look at it fall, watch an airplane passing in the sky, turn back on the scaffold, walk back to door.
Participants:		33 adult participants suffering from acrophobia. 27% male; mean age 38 years.
Study design:		Within-subjects.
Presence measures:		Witmer-Singer PQ, rating.
Person-related meas.:		Acrophobia questionnaire with Anxiety and Avoidance subscales.
Task-related measures:		Anxiety rating.
Findings:	(1)	Presence manipulation had no relationship with PQ scores.
	(2)	Anxiety rating had a significant positive correlation with presence rating.
	(3)	Acrophobia scores had no significant relationship with PQ scores.

[Nichols 2000 (1)] Nichols, S., Haldane, C., and Wilson, J. R. (2000). Measurement of presence and its consequences in virtual environments. *International Journal of Human-Computer Studies, 52,* 471–491.

Factor:	Visual display (HMD, desktop), audio cues (present, absent).
Computing platform:	Pentium 133 PC, with Superscape VRT software. Frame rate ~1 0 fps, with tracker delay of 4 ms.
Visual display:	I-glasses HMD.
Audio display:	Headphones embedded in HMD.
Navigation:	Using head movements to alter viewpoint.
Object manipulation:	Using 3D mouse.
Virtual world:	"Duck shoot" fairground stall. Percentage accuracy and number of ducks shot displayed on the screen, and participants given an incentive to perform well by being told a financial bonus would go to the top 5 high scorers. Startle event occurred between 5 and 6 min and consisted of a duck that had been hit zooming out into the foreground and "exploding." Nondirectional sound cues consisted of continual duck quacking noises with a special quack when shot.
Experimental task:	Play fairground game. 10-min time limit.
Participants:	24 undergraduate students; 12 males; age range 18 to 25. No prior experience with VEs.
Study design:	Within-subjects for type of visual display, between-subjects for audio cues.
Presence measures:	Reaction to a randomly timed "startle event," recall of different types of background music played in the lab that were out of context with the virtual world, and questionnaire.
Task-related measures:	Simulator sickness Short Symptom Checklist (SSC).
Findings: (1)	Use of HMD was associated with a significantly greater reflex response and higher scores for "being" and "visit" presence items. Visual display had no relationship with background awareness presence measure.
(2)	Use of audio cues was associated with a significantly greater reflex response. Audio cues had no relationship with presence items.
(3)	For HMD condition, total SSC scores had no significant correlation with any presence measure.

[Nichols 2000 (2)] Nichols, S., Haldane, C., and Wilson, J. R. (2000). Measurement of presence and its consequences in virtual environments. *International Journal of Human-Computer Studies, 52,* 471–491.

Computing platform:	Division ProVision 100 VPX. Frame rate range 2–15 fps, with 20-ms lag.
Visual display:	Division HMD.
Navigation:	Using head movements to alter viewpoint.
Object manipulation:	Using 3D mouse.
Virtual world:	Virtual house.
Experimental task:	Explore rooms in house and perform specified tasks in each room. (Tasks designed to ensure a range of physical movements, and both gross and small manipulation using hand-held 3D mouse.) Tasks included a 3D jigsaw puzzle, estimating reach distance and picking up pencils. 20-min time limit.
Participants:	20 participants; 10 males; age range 18 to 41; mean age 24.5 years.
Presence measures:	Witmer-Singer PQ.
Task-related measures:	Kennedy's SSQ, Adjectival Response Scale (ARS) measure of enjoyment.
Findings: (1)	PQ Interface subscale had a significant negative correlation with post-participation levels on SSQ Total and all subscales.
(2)	PQ Interface subscale had a significant positive correlation with reports of a positive experience. PQ Total and Involved/Control subscale had a significant positive correlation with overall enjoyment.

[Nicovich 2005] Nicovich, S. G., Boller, G. W., and Cornwell, T. B. (2005). Experienced presence within computer-mediated communications: Initial explorations on the effects of gender with respect to empathy and immersion. *Journal of Computer-Mediated Communication, 10* (2), Article 6.

Factors:		Interactivity (present, absent), vividness (high, low).
Computing Platform:		Microsoft Flight Simulator 98.
Visual display:		Desktop monitor.
Auditory display:		PC speakers.
Tracking:		None.
Navigation:		Using joystick.
Object manipulation:		Using joystick.
Virtual world:		As in game. High vividness condition included high resolution and sound; low vividness used lower resolution and no sound.
Training:		Instruction on how to use the game controls and the meaning of readouts. Practice with game until a level of comfort was demonstrated with the plane and joystick controls.
Experimental task:		Participants in interactivity condition given a take-off and landing task, 10 min allowed. Participants in the no interactivity condition watched a prerecorded video of the same game scenario.
Participants:		184 graduate and undergraduate students; 89 males; age range 18 to 54.
Study design:		Between-subjects.
Presence measures:		5-item questionnaire.
Person-related meas.:		Gender.
Task-related measures:		5-item empathy questionnaire.
Findings:	(1)	Use of interactivity was associated with significantly higher presence scores.
	(2)	Participants reported significantly higher presence scores for high vividness.
	(3)	In the interactive condition, empathy had no significant correlation with presence.
	(4)	In the high-vividness condition, gender had no significant association with presence.
	(5)	In the interactive condition, gender had a significant association with presence, with males reporting significantly less presence than women in the noninteractive condition and significantly more presence than women in the interactive condition.
	(6)	The interaction of gender and interactivity had a significant association with presence, with males reporting more presence in the interactive conditions than in the noninteractive condition.

[Noel 2004] Noel, S., Dumoulin, S., Whalen, T., Ward, M., Stewart, J., and Lee, E. (2004). A breeze enhances presence in a virtual environment. *Proceedings of the 3rd IEEE International Workshop on Haptic, Audio, and Visual Environments and Their Applications – HAVE 2004,* Ottawa, Canada, October, 63–68.

Factors:	Haptic feedback (self-generated breeze, object-generated breeze, natural breeze, no breeze).
Computing platform:	Pentium III with dual 1-GHz processors, NVIDIA GeForce III video card. Software used VRML97 markup with FreeWRL VRML browser.
Visual display:	Virtual Research V8 HMD. Frame rate ~ 25 fps.
Haptic display:	Breeze cannon constructed from a bathroom ventilation fan blowing 110 ft^3 of air through a 3-in. diameter nozzle. Fan ran continuously and was manually controlled to one of 3 levels: no breeze, weak breeze, strong breeze. Nozzle placed 60 cm from participant's face. Self-generated breeze caused breeze cannon to be activated whenever the participant moved through the virtual world, with speed determining breeze strength. An object-generated breeze was synchronized with the movement

	of the virtual airplanes in front of the participant's avatar. In the natural breeze condition, a breeze was provided for ~ 10 sec in every minute.
Tracking:	Head tracking using Polhemus 6 DOF motion tracker mounted on chair.
Navigation:	Computer joystick.
Object manipulation:	None.
Virtual world:	Urban park with ~ 300 widely spaced simple pine trees, 4 differently colored houses randomly placed one in each quadrant and a fifth house near the center of world. Each house had a colored beacon on its roof that lit up when that house was the next to be visited. Each house turned white when participant got near to it. Each quadrant had a different backdrop: urban skyline, mountain chain, wheat field, moor. Six objects represented radio-controlled airplanes, one circling around each house. The sixth object followed a circular trajectory around the participant. Forest sounds, including bird songs, played in a continuous loop at a low level to block background noises.
Training:	Training in using the joystick, ~ 1 min. Then, practice trial with houses also marked with a colored pole on each roof.
Experimental task:	Guided by the order in which beacons lit up, visited each house in turn as quickly as possible. 4 trials (with presence questionnaire delivered after each).
Participants:	8 participants; 3 males; age range 26 to 48; mean age 35 years.
Study design:	Within-subject.
Presence measures:	4-item version of Prothero's presence questionnaire.
Task-related measures:	Kennedy's SSQ, awareness and ratings of breeze questionnaire (completed at end of last trial).
Performance measures:	*Time to complete*.
Findings: (1)	Haptic feedback had a significant relationship with only the first presence item (whether felt in lab or VE), with more presence reported for the self-generated breeze condition than for each of the object-generated and no-breeze conditions.
(2)	*Haptic feedback had no significant relationship with time to complete the task.*

[Nowak 2003] Nowak, K. L., and Biocca, F. (2003). The effect of agency and anthropomorphism on users' sense of telepresence, copresence, and social presence in virtual environments. *Presence*, *12* (5), 481–494. See also Nowak, K. (2001). Defining and differentiating copresence, social presence and presence as transportation. *Proceedings of the 4th Annual International Workshop on Presence,* Philadelphia, USA, May.

Factors:	Anthropomorphism (high, low, no image), perceived agency (told human-controlled avatar, told computer-controlled avatar).
Visual display:	19-in. desktop monitor.
Auditory display:	Headphones and microphone.
Tracking:	None.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Meeting room with a sign indicating that participants were in a scavenger hunt meeting place. Virtual partner represented by a female virtual face, abstract face, or no image; participant selection of face used when image provided.
Experimental task:	Participants were told either that they were interacting with a computer-controlled agent or a human-controlled avatar. They had to get to know their partner with whom they may work in future on a scavenger hunt. All partner responses using a pre-recorded female voice reading from a script. Average interaction lasted about 15 min.
Participants:	134 undergraduates; 94 males; age range 19 to 33; mean age 21 years.
Study design:	Between-subjects.
Presence measures:	5-item presence questionnaire, 12-item perceived other's co-presence questionnaire, 6-item self-reported co-presence questionnaire, 6-item social presence questionnaire.

Findings:	(1)	Perceived agency had no significant relationship with presence, perceived other's co-presence, self-reported co-presence, or social presence.
	(2)	Anthropomorphism had no main effect on presence but had a significant interaction effect with agency, such that more presence was reported when a partner was represented by an image. Those in the low anthropomorphism group reported significantly less presence than those in the high anthropomorphism group.
	(3)	Participants reported significantly higher scores for perceived other's co-presence, self-reported co-presence, and social presence for low anthropomorphism than for high or no image.
	(4)	Perceived other's co-presence had a significant positive correlation with presence and social presence.
	(5)	Self-reported co-presence had a significant positive correlation with presence and social presence.
	(6)	Social presence had a significant positive correlation with presence, perceived other's co-presence, and self-reported co-presence.

[Nuñez 2003a] Nuñez, D., and Blake, E. (2003a). A direct comparison of presence levels in text-based and graphics-based virtual environments. *Proceedings of the 2nd International Conference on Computer Graphics, Virtual Reality, Visualization and Interaction in Africa*, Cape Town, South Africa, February, 53–56.

Factors:		Visual and auditory quality (high, low, text).
Visual display:		High-quality graphics version rendered at $640 \times 480 \times 16$ resolution, including textures, radiosity, and sound, with 17-Hz refresh rate.
Audio display:		Stereo headphones.
Navigation:		For high- and low-quality graphics and sound versions, quake keys navigation method using mouse to change view yaw and pitch, and keyboard for achieving walking motion. For text version, using key commands from menus.
Object manipulation:		None.
Virtual world:		Medieval monastery. Graphics/sound versions rendered at $640 \times 480 \times 16$ resolution. Two versions contained containing 18 furnished rooms over 3 levels, connected by 2 stairways, included textures, radiosity, and sound. The low-quality version used flat shaded polygons and no sound. Text version contained 27 rooms (counting long passageways and stairways), 20 of which had a text descriptions accompanied by a $280 \times 100 \times 8$ resolution still image. Text descriptions only included information available in the graphics/sound versions.
Training:		Practice with system, in a different virtual world, for 5 min.
Experimental task:		Explore monastery, locating 20 boxes positioned throughout the building. 15 min allowed.
Participants:		78 students, mostly 1st year science students.
Study design:		Between-subjects.
Presence measures:		6-item SUS Questionnaire, Witmer-Singer PQ.
Findings:	(1)	Participants gave significantly higher SUS scores for high quality than for low quality or text.
	(2)	Participants gave significantly higher PQ scores for high quality than for low quality or text, and for low quality than for text.

[Nuñez 2003b] Nuñez, D., and Blake, E. (2003b). *The thematic baseline technique as a means of improving the sensitivity of presence self-report scales.* Paper presented at the 6th International Workshop on Presence, Aalborg, Denmark, October. See also Nuñez, D., and Blake, E. (2003c). Conceptual priming as a determinant of presence in virtual environments. *Proceedings of the 2nd International Conference on Computer Graphics, Virtual Reality, Visualization, and Interaction in Africa*, Cape Town, South Africa, February, 101–108.

Factor:		Visual and auditory quality (high, low), priming (related materials, unrelated materials).
Computing platform:		AMD Athlon 700-MHz PC, with GeForce 2 MX graphic card. DIVE software system.
Visual display:		17-in. desktop monitor for presentation of stereo sound.
Audio display:		Stereo headphones.
Navigation:		Quake keys navigation method using mouse to change view yaw and pitch and keyboard for achieving walking motion.
Object manipulation:		None.
Virtual world:		One virtual world was a medieval monastery consisting of 16 rooms over 3 levels. The second virtual world was a contemporary hospital with 15 rooms over 4 levels.
Training:		Third virtual building used for training, consisting of 12 rooms spread over 3 levels. The high-quality versions used textures, radiosity, and 3D sound. The low-quality versions used flat shaded polygons and no sound.
Experimental task:		After reading priming material, explore virtual world. 15 min allowed. 1 trial in each of 2 virtual worlds, with presence data collected after each.
Study design:		Between-subjects.
Participants:		55 undergraduate students; in early 20s.
Presence measures:		Witmer-Singer PQ, SUS Questionnaire.
Findings:	(1)	Participants gave significantly higher PQ and SUS scores for high quality than for low quality or text.
	(2)	Priming had no significant relationship with either presence measure. There was a significant interaction with visual and auditory quality, such that there was a difference for visual and auditory stimulus only when participants were primed with related materials.

[Nystad 2004] Nystad, E., and Sebok, A. (2004). A comparison of two presence measures based on experimental results. *Proceedings of the 7th Annual International Workshop on Presence*, Valencia, Spain, October, 266–273.

Factor:	Visual display (HMD with head tracking, large screen with stereo, desktop display with stereo, desktop display).
Computing platform:	VRTexp training application developed using extended version of XJ3D.
Visual display:	HMD, desktop monitor.
Tracking:	Head tracking for HMD.
Navigation:	Using mouse.
Object manipulation:	Using mouse.
Virtual world:	Representation of a nuclear reactor hall.
Training:	10-min practice scenario to gain familiarity with navigating and selecting objects.
Experimental task:	Learn an 8- to 12-step control-station changeout maintenance procedure in a nuclear reactor setting. Four 30- to 60-min training sessions, each starting with passive viewing before active performance.
Participants:	24 employees at the Organisation for Economic Co-operation and Development (OECD) Halden Reactor Project (HRP); 22 males; age range 25 to 61.
Study design:	Between-subject with each participant using 3 of the 4 visual display types. Half of the participants responded using PQ, and half responded using SUS Questionnaire.

Presence measures:		Witmer-Singer PQ, SUS Questionnaire.
Person-related meas.:		Rating of familiarity with the real reactor hall depicted in the VE, Witmer-Singer ITQ.
Task-related measures:		Brooks 10-item usability questionnaire.
Performance measures:		Number of incorrect actions during training, recall of procedural steps and tools used while looking at pictures of reactor hall for retention test taken 1 day later.
Findings:	(1)	Visual display had no significant relationship with presence as measured using either the PQ or SUS Questionnaire.
	(2)	Usability had a significant positive correlation with PQ (Total) and PQ Involved Control and PQ Interface Quality subscales but had no relationship with SUS Questionnaire.
	(3)	Errors during training had a significant, negative correlation with SUS Questionnaire only in 3rd active repetition. No correlation with PQ.
	(4)	Retention test results showed a significant negative correlation between error tool count and the SUS Questionnaire and a significant positive correlation with PQ Interface Quality subscale. No relationship for procedural errors.
	(5)	Familiarity with the environment had a significant, positive correlation with SUS Questionnaire but not with PQ.
	(6)	ITQ (Total) and ITQ Involvement subscale had a significant positive correlation with the SUS Questionnaire. ITQ (Total) and ITQ Focus subscale had a significant negative correlation with the PQ Natural subscale.

[Olsson 2001] Olsson, M., Vien, K., Ng, E., So, R., and Alm, H. (2001). Effects of vection on the sense of presence in a virtual environment. *Proceedings of the 9th International Conference on Human-Computer Interaction,* New Orleans, USA, August, 654–658.

Factors:		Vection (present, absent).
Computing platform:		SGI Onyx II station. Simulation generated using WorldToolKit Release 8.
Visual display:		VR4 HMD.
Tracking:		Head and hand tracking using Polhemus 3Space.
Object manipulation:		Using Cyberglove.
Virtual world:		Acoustic room, 4.8 × 11.7 m, with table in front of participant. Virtual monitor, speakers, push buttons, cubes, and cylinders on table. In condition with vection, at 5, 12, 19, and 26 min, perform virtual navigation tour in the fore-and-aft and lateral directions around the room. Speed of travel 1 m/sec, duration of tour 2 min. Navigation tour combined with visual search tasks. Visual search task requiring same head movements performed by participants in nonvection condition. 30 min.
Training:		Guided viewing of virtual room. 2 min.
Experimental task:		Perform series of sound localization, visual search, and object manipulation tasks.
Participants:		24 students; 12 males; age range 20 to 24.
Study design:		Between-subjects.
Presence measures:		PQ, modified 5-item SUS Questionnaire.
Person-related meas.:		*Motion Sickness Susceptibility Survey (MSSS), ITQ*.
Task-related measures:		*Kennedy SSQ*, *7-point nausea rating*, *vection rating*.
Findings:	(1)	Vection had no significant relationship with either PQ or SUS scores.
	(2)	SUS scores had a significant positive correlation with PQ Involvement/Control, Natural, and Haptic subscale scores and with PQ Total scores.

[Otto 2005] Otto, O., Roberts, D., and Wolff, R. (2005). A study on influential factors on effective closely-coupled collaboration based on single user perceptions. *Proceedings of the 8th International Workshop on Presence*, London, UK, September, 181–188.

Factors:	Visual display (Cave, workbench, desktop monitor).

Computing platform:	DIVE 3.3.5 with event monitoring plug-in for monitoring user and object movements for post-trial analysis.
Visual display:	Cave, workbench, desktop monitor.
Object manipulation:	Joystick for Cave and workbench; mouse and keyboard for monitor.
Virtual world:	Simple field with items needed for task.
Training:	Perform experimental task using desktop system. 3 trials to become familiar with interface and task. Additional trial (for comparison with other displays).
Experimental task:	Build a simple structure using wooden beams, metal joiners, and screws using a set of tools in a specific order. Objects had to be carried to construction site. Gravity disabled to allow a single participant to perform the task (previously used in a collaborative setting). Task took 5 to 10 min.
Participants:	13 students.
Presence measures:	3-items included in general questionnaire.
Task-related measures:	*Questionnaire covering perception of performance, interface, FOV, interaction with objects.*
Performance measures:	*Time taken on a test-run.*
Findings: (1)	Participants reported significantly less presence for desktop monitor.
(2)	*Participants perceived performance to be significantly lower using the desktop system.*
(3)	*Participants reported the monitor mouse/keyboard interface impeded them more significantly than the immersive system interfaces.*
(4)	*Participants rated the FOV as significantly more important in the immersive systems.*
(5)	*Participants reported missing the sense of touch significantly more in the desktop system.*
(6)	*Type of display had no significant relationship with performance time.*

[Patel 2006] Patel, K., Bailenson, J. N., Hack-Jung, S., Diankov, R., and Bajcsy, R. (2006). The effects of fully immersive virtual reality on the learning of physical tasks. *Proceedings of the 9th International Workshop on Presence*, Cleveland, USA, August, 129–138.

Factors:	Environment type (immersive VR, video).
Visual display:	Projection screen viewed with polarized glasses for stereoscopic viewing while learning moves. Desktop monitor for review, again using polarized glasses.
Tracking:	Motion capture.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Presentation of virtual teacher. In virtual condition, in addition to front view, participant saw image of self rendered in 3rd person, image of teacher from behind, and reflection of both images in a virtual mirror. Name of each Tai Chi move shown above teacher’s head. Virtual teacher’s moves captured from Tai Chi expert. Each move shown 3 times.
Experimental task:	Phase 1: watch and mimic teacher to learn 3 Tai Chi moves. Phase 2: review performance using videotapes recorded during previous phase. In VE condition, participants had control over playback, received depth cues, and could see 3D rendering of themselves superimposed over teacher’s moves. 10 min. Phase 3: repeat Phase 1. Phase 4: participants tested on moves by being asked to recreate motions without seeing teacher; video recorded for judging.
Participants:	26 undergraduates; 13 males.
Study design:	Between-subjects.
Presence measures:	10-item social presence questionnaire (used data from 3 items).
Performance measures:	*4-item subjective task performance questionnaire, judging by blind coders.*
Findings: (1)	Participants recorded significantly higher social presence for immersive VR.
(2)	*Environment type had no significant relationship with subjective performance scores.*

(3) *Participants who learned in the immersive VR were judged to perform significantly better than those who learned from video.*

[Petzold 2004] Petzold, B., Zaeh, M. F., Faerber, B., Demi, B., Egermeier, H., Schilp, J., and Clarke, S. (2004). A study on visual, auditory, and haptic feedback for assembly tasks. *Presence, 13* (1), 16–21.

Factors:	Haptic force feedback (delivered to fingertip, none), audio feedback (sound of collisions, absent), visual force feedback (bar graph of force strength/direction, absent).
Computing platform:	Virtual Engineering Environment (Ve^2) (based on WorldToolKit) for visual rendering, Solid 3.1 for collision detection.
Visual display:	Desktop monitor.
Tracking:	None.
Navigation:	None.
Object manipulation:	SensAble Technologies PHANTOM force-feedback device.
Virtual world:	Representation of a flat surface with a gear shaft mounted on a virtual fixture, gear wheel also shown.
Training:	Learning how to use the PHANTOM, then one task trial.
Experimental task:	Mount a gear wheel on a gear shaft as fast as possible.
Participants:	48 participants.
Study design:	Between-subjects.
Presence measures:	Presence questionnaire with subscales Spatial Presence, Quality of Interface, Emotional Involvement.
Performance meas.:	Task completion time.
Findings:	(1) Participants with haptic force feedback gave significantly higher presence. There were significant interactions with auditive and visual feedback, such that more presence was reported when visual or auditive feedback was provided. (2) Audio feedback had no significant relationship with presence. (3) Visual feedback on forces exerted had no significant relationship with presence. (4) Task completion time had a significant negative correlation with total presence scores. *(5) Haptic force feedback, audio feedback, and visual force feedback had no significant association with task completion time.*

[Preston 1998] Preston, L. (November 1998). *The use of virtual reality in the reduction of stress*. Honours thesis, Rhodes University, Grahamstown, South Africa.

Factor:	Level of interaction (interaction with VE, watching video through HMD).
Computing platform:	SGI O2. RhoVeR software system with CoRgi Toolkit.
Visual display:	General Reality CyberEye HMD. Frame rate 6–8 fps. Participants seated in a swivel chair positioned in a darkened room.
Audio display:	HMD headphones.
Tracking:	Polhemus InsideTrak for head and hand tracking.
Navigation:	Using a hand-held stick with 4 switches to control movement.
Object manipulation:	Using the hand-held stick, clicking switches to move corresponding fingers on virtual hand.
Virtual world:	Derived from SGI's underwater demo environment where participant can interact with a range of marine mammals and modified so that dolphins show curiosity about the diver and spend a portion of their time in the diver's vicinity. Participants swim around, touch a dolphin or swaying sea plant, and ride a dolphin. Images constructed from smoothed and shaded polyhedral objects with texture mapping. Musical background. Self-representation as virtual hand.
Experimental task:	Swim with dolphins. 5-min time limit.

Participants:		35 university students; 23 males; 4 participants between 10 and 20 years, 31 participants between 21 and 30 years.
Study design:		Within-subjects.
Presence measures:		Δheart rate. Also 1-item presence questionnaire.
Finding:	(1)	Level of interaction had no significant relationship with Δheart rate.

[Price 2006] Price, M. (2006). *The relation of presence and virtual reality exposure for treatment of flying phobia*. Master's dissertation, Georgia State University, Atlanta, College of Arts and Sciences.

Visual display:		HMD.
Auditory display:		Headphone for traditional flight sounds. Therapist also used microphone that broadcast to HMD.
Training:		Patients underwent 8 individual sessions of treatment across 6 weeks. First 4 sessions consisted of anxiety management and skills training, including breathing relaxation, and cognitive restructuring.
Experimental task:		Exposure to VE in final 4 sessions (twice a week). Exposure sessions conducted according to a fear hierarchy: sitting on plane with engine off, sitting on plane with engines on, taxiing on runway, takeoff, a smooth flight, landing, turbulent flight.
Participants:		36 patients meeting DSM-IV anxiety criteria, with flying as the predominantly feared stimulus.
Presence measures:		Shortened Witmer-Singer PQ.
Person-related meas.:		33-item Fear of Flying Inventory (FFI), 36-item Questionnaire on Attitudes Toward Flying (QAF). Both taken pre-treatment, post-treatment.
Task-related measures:		SUDS, taken mid-session.
Findings:	(1)	Presence had a significant relationship with in-session anxiety and "fully mediated" the relationship between pre-treatment anxiety and in-session anxiety.
	(2)	Presence had no significant relationship with post FFI scores.
	(3)	Presence had a significant positive correlation with the amount of phobic elements (counted based on the number of QAF items included in virtual world).

[Priore 2003] Priore, C. L., Castelnuovo, G., Liccione, D(iego)., and Liccione, D(avide). (2003). Experience with V-STORE: Considerations on presence in virtual environments for effective neuropsychological rehabilitation of executive functions. *CyberPsychology & Behavior, 6* (3), 281–287.

Factors:	Type of visual display (HMD, desktop monitor).
Computing platform:	V-Store system for cognitive (executive function) rehabilitation.
Visual display:	HMD, desktop monitor.
Audio display:	Stereo speakers.
Tracking:	3 DOF tracking device for head tracking with HMD.
Navigation:	Joystick.
Object manipulation:	Joystick buttons for picking up/dropping objects.
Virtual world:	Inside of a goods store.
Training:	8-min practice with V-Store environment, objects, and commands.
Experimental task:	Two series of tasks ordered in ascending level of difficulty. Participant explores a goods store to solve a series of tasks, such as putting pieces of fruit into a basket according to an imparted disposition. Distracting elements used to generate time pressure and elicit managing strategies. Radio broadcast presented over audio speakers. Each series of tasks took 8 min.
Participants:	12 participants. No reported neurological or psychiatric problems.
Study design:	Between-subjects.
Presence measures:	ITC-SOPI questionnaire, Δskin conductance (galvanic skin response (GSR) recorded using Psycholab VD13)), BIPs, incidental memory (assessed using answers to questions on radio broadcast).

Findings:	(1)	Use of HMD was associated with significantly higher Δskin conductance. Task difficulty had no significant relationship with Δskin conductance.
	(2)	Use of HMD was associated with significantly higher ITC-SOPI Negative Effects scores.
	(3)	Type of visual display had no significant relationship with presence as assessed by the incidental memory and breaks in presence measures.

[Prothero 1995a (1)] Prothero, J. D., Hoffman, H. G., Parker, D. E., Furness III, T. A., and Wells, M. J. (1995a). Foreground/background manipulations affect presence. *Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting: Human Factors Society,* San Diego, USA, October, 1010–1014.

Factors:	Visual scene (as foreground, as background).
Computing platform:	Division ProVision 100 system.
Visual display:	Division dVisor HMD with 40° V × 105° H, 40° overlap. Eye mask provided by Lucas Products Corporation. Super Sunnies tanning goggles with central ultraviolet (UV) protectors removed, providing FOV 40° direct and 60° peripheral or screen mask provided by paper mask mounted on HMD screens with 2.54-cm diameter holes providing FOV 60°.
Object manipulation:	Virtual net slaved to real hand position.
Virtual world:	Division SharkWorld: a texture mapped underwater scene with a sunken ship and various moving sea creatures.
Experimental task:	Catch sharks using a virtual net. 2.5-min time limit.
Participants:	26 adults; 19 males. 3 participants reported more than 10-min prior VE experience.
Study design:	Within-subjects.
Presence measures:	Questionnaire.
Findings: (1)	Perceiving a virtual scene as background was associated with significantly higher presence total score and for each item.
(2)	Order had a significant effect, such that the difference between conditions was significant only when the eye mask was used first.

[Prothero 1995a (2)] Prothero, J. D., Hoffman, H. G., Parker, D. E., Furness III, T. A., and Wells, M. J. (1995a). Foreground/background manipulations affect presence. *Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting: Human Factors Society,* San Diego, USA, October, 1010–1014.

Factors…	
Presence measures:	As in [Prothero 1995a (1)], except for participants: 13 adults; 9 males. One participant reported more than 10-min prior VE experience. Conducted as double-blind experiment.
Findings: (1)	Perceiving a virtual scene as background was associated with significantly higher presence scores.

[Prothero 1995b] Prothero, J. D., and Hoffman, H. G. (1995b). *Widening the field-of-view increases the sense of presence in immersive virtual environments* (Technical Report TR-95-2). Seattle, WA: University of Washington, Human Interface Technology Laboratory (HITLab).Available: http://www.hitl.washington.edu/publications/r-95-5/

Factors:	Field of view (unrestricted 40° V × 105° H, restricted (direct 40°, peripheral 60°)).
Computing platform:	Division ProVision 100 system.
Visual display:	Division dVisor HMD with 40° V × 105° H, 40° overlap. Eye mask provided by Lucas Products Corporation. Super Sunnies tanning goggles with central UV protectors removed.
Tracking…	
Experimental task:	As in [Prothero 1995a (1)].

Participants:		38 high school students; 20 males; age range 16 to 18. No participants reported more than 10-min prior VE experience.
Study design:		Within-subjects.
Presence measures:		5-item presence questionnaire.
Person-related meas.:		Gender.
Findings:	(1)	Participants gave significantly higher presence for unrestricted FOV. When analyzed separately, a significant difference was found for only 2 items (felt like standing in lab as opposed to the virtual world, reality of the virtual world).
	(2)	Gender had a significant association with presence.
	(3)	Order had a significant effect on presence, such that the difference between conditions was significant only when the eye mask was used first.

[Rand 2005] Rand, D., Kizony, R., Feintuch, U., Katz, N., Josman, N., Rizzo, A. A., and Weiss, P. L. (2005). Comparison of two VR platforms for rehabilitation: Video capture versus HMD. *Presence, 14* (2), 147–160.

Factors:		VR platform (Gesture Xtreme-monitor, GX-HMD)), gender, age.
Computing platform:		VividGroup's (now GestureTek) Gesture Xtreme projected video-capture VR platform.
Visual display:		5DT HMD 800 or enlarged monitor.
Tracking:		InterSense InterTrax2 head tracking for HMD system.
Navigation:		For HMD system, using 2 hand-held switches to move to left or right.
Virtual world:		GestureTek's GX100 Birds & Balls, Soccer GX, and Snow Boarding (avoid obstacles as skiing downhill). Virtual Office (developed by the University of Southern California) in which the participant scans the office for 2 to 5 min in order to determine objects that did not belong (8 of 16 objects).
Experimental task:		Play games or, in Virtual Office, identified odd objects.
Participants:		89; 40 aged 16 to 35 and 49 aged 60 to 75.
Study design:		Mixed design, with elderly participants using Virtual Office world only.
Presence measures:		19-item Witmer-Singer PQ, 6-item Scenario Presence Questionnaire (SPQ).
Task-related measures:		*20-point Borg's Scale of Perceived Exertion*, *Kennedy SSQ*.
Performance measures:		*Game score (for Virtual Office, visual scanning memory recall*, *scanning time)*.
Findings:	(1)	For the 3 games, participants gave significantly higher PQ scores for the GX monitor platform. Gender and age had no significant relationship with PQ scores.
	(2)	For the 3 games, SPQ scores did not distinguish between platform or gender. When analyzed separately, males gave significantly higher scores for Snow Boarding.
	(3)	For Virtual Office, gender had a main effect for GX-monitor with males reporting significantly higher PQ scores.
	(4)	For Virtual Office, platform and age had an interaction, such that, using the HMD, older participants reported significantly higher PQ scores.
	(5)	For Virtual Office and the HMD, older participants gave significantly higher SPQ scores.
	(6)	*For Birds & Balls, game score was significantly higher for GX-monitor. Gender had no significant relationship with game score.*
	(7)	*For Soccer GX, males scored significantly higher than females. Platform has no relationship with game score.*
	(8)	*For Snow Boarding, platform and gender had no significant relationship with game score.*
	(9)	*For games, SSQ scores were significantly lower for GX monitor.*
	(10)	*For games, Borg scale scores were not significantly different for platform and gender.*
	(11)	*For Virtual Office, participants' visual scanning and scanning time were significantly better for GX monitor. Recall was significantly better for HMD.*
	(12)	*For Virtual Office, SSQ scores were significantly lower for GX monitor.*

(13) *For Virtual Office, younger participants reported significantly more exertion than older participants.*

[Rand 2004 (1)] Rand, D., Kizony, R., and Weiss, P. L. (2004). Virtual reality rehabilitation for all: Vivid GX versus Sony PlayStation II EyeToy. *Proceedings of the 5th International Conference on Disability, Virtual Reality, and Associated Technology*, Oxford, UK, September, 87–92.

Factors: VR platform (EyeToy, Gesture Xtreme).
Computing platform: VividGroup (now GestureTek) GX System.
Virtual world: Motion games. For GX: Birds & Balls—touching, approaching balls game, Soccer GX—protecting balls from entering goal crease game. Sony PlayStation EyeToy: Wishy-Washy cleaning windows game, Kung-Foo fighting game.
Experimental task: Play 2 games for 3 min each.
Participants: 18 participants; 1 male; age range 21 to 37; mean age 25.3 years. Mainly university students.
Study design: Within-subjects.
Presence measures: 19-item Witmer-Singer PQ, 1 item based on SUS Questionnaire. Completed after first 2 games with one of the systems, then after next 2 games with other system.
Task-related measures: 6-*item SFQ*, *20-point Borg's Scale of Perceived Exertion*.
Findings:
(1) Participants' PQ scores for each platform were not significantly different. Similarly, there was no significant difference for presence ratings.
(2) *Participants' SFQ ratings for Kung-Foo were significantly higher than scores for Birds & Balls and Soccer GX.*
(3) *Participants' rating of enjoyment (1st item of SFQ) for Kung-Foo was significantly higher than enjoyment given for each of the other games.*
(4) *Birds & Balls was perceived to require significantly less exertion than the other games.*

[Ravaja 2006] Ravaja, N., Saari, T., Turpeinen, M., Laarni, J., Salminen, M., and Kivikangas, M. (2006). Spatial presence and emotions during video game playing: Does it matter with whom you play? *Presence, 15* (4), 381–392.

Factors: Game content (FPS, nonviolent game), game opponent (friend, stranger, computer).
Computing platform: Nintendo Game Boy Advance console.
Virtual world: FPS game was Duke Nukem Advance. Nonviolent game was Super Monkey Ball.
Training: Practice with each game in single-player mode for 5 min.
Experimental task: Play each game for 8 min against different opponents. These 6 sessions were in randomized order.
Participants: 33 groups of 3 Finnish undergraduates (same-sex groups); 51 males; age range 19 to 34; mean age 23.8 years.
Study design: Within-subjects.
Presence measures: 37 items covering ITC-SOPI Spatial Presence, Engagement, and Ecological Validity/Naturalness subscales.
Task-related measures: *Self-report emotional response: 9-point pictorial valence scale, 9-point pictorial arousal scale*. Objective measures of arousal and emotional valence: ECG and cardiac interbeat intervals (IBIs) (using Psylab Model BIO2 from Contact Precision Instruments, London, UK); facial electromyography (EMG) from left corrugator supercilii, zygomaticus major, and orbicularis oculi muscles regions (using silver-silver chloride (Ag/AgCI) electrodes from Med Associates, Inc., St. Albans, Vermont)). *Pre-ratings of expected game violence, post-rating of game challenge*.
Findings:
(1) Participants gave significantly higher ITC-SOPI Spatial Presence and Engagement scores for playing against another person (friend or stranger) and for playing against a friend compared with a stranger.

(2) Participants gave significantly higher ITC-SOPI Ecological Validity/Naturalness scores for Duke Nukem compared to Super Monkey Ball.

(3) ITC-SOPI Engagement scores had a significant positive correlation with zygomatic and orbicularis oculi EMG responses during Super Monkey Ball.

(4) Participants gave significantly higher threat ratings when about to play against a human as compared with playing against a computer.

(5) Game opponent had no significant relationship with post-game challenge ratings.

(6) Participants had significantly more positive self-reported emotional response for playing against another person as compared with a computer.

(7) Participants gave significantly higher self-reported arousal for playing against a friend as compared with playing against a stranger.

(8) IBIs were significantly shorter when participants played with another human as compared with playing against a computer and significantly shorter for playing against a friend as compared with playing against a stranger.

(9) Zygomaticus major EMG activity was significantly higher when playing against a human as compared with playing against a computer and significantly higher when playing against a friend as opposed to playing against a stranger. Corrugator supercilii EMG activity was significantly higher when playing against a computer, and significantly lower when playing against a friend compared with a playing against stranger. Orbicularis oculli activity was significantly higher when playing against a computer and significantly higher when playing against a friend as compared with when playing against a stranger.

[Ravaja 2004a] Ravaja, N., Salminen, M., Holopainen, J., Saari, T., Laarni, J., and Järvinen, A. (2004a). Emotional response patterns and sense of presence during video games: Potential criterion variables for game design. *Proceedings of the 3rd Nordic Conference on Human-Computer Interaction*, Tampere, Finland, October, 339–347.

Factors:	Game content (*Tetris*, *Super Monkey Ball 2*, *Monkey Bowling 2*, *James Bond 007: NightFire*), game level (easy, difficult).
Computing platform:	Nintendo GameCube.
Visual display:	Screen (114 × 85 cm image) with Panasonic PT-LC75E Multimedia Projector.
Training:	5-min practice session for each game.
Experimental task:	Two 5-min sessions: for each game, 1 at easy level and 1 at difficult level.
Participants:	37 undergraduates; 26 males; age range 20 to 30. All played video or computer games at least once a month.
Study design:	Within-subjects.
Presence measures:	37-item ITC-SOPI (excluding Negative Effects).
Person-related meas.:	19-item ZKPQ-ImpSS scale, 11-item Self-Forgetful versus Self-Conscious Experiment Scale.
Task-related measures:	*Game interest rating*, *game goodness rating*, *9-item pictorial Valence scale*, *9-item pictorial arousal scale*, *5-topic mood scale consisting of 2- or 3-item scales for of joy*, *pleasant relaxation*, *fear*, *anger*, *and depressed feeling*.

Findings:

(1) James Bond 007 was given significantly higher Spatial Presence scores.

(2) Games played at the difficult level were given significantly higher Spatial Presence scores. There was a significant interaction with Self-forgetfulness, such that, at the easy level, highly self-forgetful participants reported higher spatial awareness compared to low self-forgetful participants.

(3) James Bond 007 and Super Monkey Ball 2 were given significantly higher Engagement scores. There was a significant interaction with ImpSS, such that James Bond 007 scores higher Engagement among high ImpSS scores compared to low scorers, while the reverse held for other games.

(4) Monkey Bowling 2 scored significantly lower interest ratings. Tetris received significantly higher game goodness rating than Super Monkey Ball 2 and James Bond 007, which scored significantly higher than Monkey Bowling 2.

(5) *Super Monkey Ball 2 received significantly higher Valence scores than Tetris. Monkey Bowling 2 and James Bond 007 scored lowest.*

(6) *Super Monkey Ball 2 and James Bond 007 received significantly higher Arousal scores. Games played at the difficult level received significantly higher Arousal scores.*

(7) *Super Monkey Ball 2 received significantly higher Joy scores. James Bond 007 received significantly higher Pleasant relaxation, Anger, and Fear scores. Monkey Bowling 2 received significantly higher Depressed scores.*

[Ravaja 2004b] Ravaja, N., Laarni, J., Kallinen, K., Saari, T., Salminen, M., Holopainen, J., and Järvinen, A. (2004b). Spatial presence and emotional responses to success in a video game: A psychophysical study. *Proceedings of the 7th Annual International Workshop on Presence*, Valencia, Spain, October, 112–116.

Computing platform:	Nintendo GameCube.
Visual display:	Panasonic PT-LC75E projector and screen. Image size 114 × 85 cm.
Virtual world:	Super Monkey Ball 2.
Training:	Practice session played at Beginner level.
Experimental task:	2 play sessions: one at Beginner and one at Advanced level.
Participants:	36 undergraduates; 25 males; age range 20 to 30. All played video or computer games at least once a month.
Presence measures:	ITC-SOPI Spatial Presence subscale taken after each session.
Task-related measures:	ECG and IBIs (using Contact Precision Instrument's Psylab Model BIO2 isolated AC amplifier), facial EMG activity (orbicularis oculi, corrugator supercilii), electrodermal activity (EDA) skin conductance level.
Performance measures:	Time taken to reach game goal.

Findings:

(1) Reaching goal had an interaction with presence for ECG, significant increase for participants reporting high presence and significant decrease for participants reporting low presence.

(2) Reaching goal had an interaction with presence for EMG corrugator supercilii activity, significant decrease for participants reporting high presence.

(3) Reaching goal had an interaction with presence for skin conductance level, significant decrease for participants reporting low presence.

(4) Reaching goal had no significant interaction with presence for IBI.

[Razzaque 2002] Razzaque, S., Swapp, D., Slater, M., Whitton, M. C., and Steed, A. (2002). Redirected walking in place. *Proceedings of the Workshop on Virtual Environments 2002,* Barcelona, Spain, May, 123–130.

Factors:	Turning method (Redirected walking in place (RWP), hand-held controller)).
Computing platform:	SGI Onyx2 with 8 R12000 MIPS processors, 4 InfiniteReality2 graphics pipes generating imagery at 22.5 fps.
Visual display:	Trimension ReaCToR Cave (3 sides and floor), with participants using CrystalEyes shutter glasses.
Tracking:	InterSense IS-900 head tracking, torso tracking using IS-900 wand attached to participant's waist.
Navigation:	For RWP condition, a neural network analyzed head motion data in real time, providing a latency of ~ 0.25 to 0.5 sec between a participant starting to wall-in-place and the neural net detecting that movement. Logitech wireless mouse used as hand-held controller.
Object manipulation:	None.
Virtual world:	Brick room with several windows, pictures, pedestals, light stands, and 4 signs on the walls. Participants in the RWP condition were redirected by rotating the view of the virtual world, such that the participant is made to continuously turn toward

		the front wall of the Cave, where the amount of rotation is a function of the participant's orientation, linear velocity, and angular velocity.
Training:		Familiarization with equipment and practice with walking-in-place.
Experimental task:		Find and read 4 signs ("Alarm," "Halon,", "Practice," "Window") and then revisit them in alphabetical order.
Participants:		28 participants.
Study design:		Between-subjects.
Presence measures:		6-item SUS Questionnaire.
Person-related meas.:		Degree status.
Task-related measures:		Saw_back_wall occurrence (back wall within 40º FOV of participant), rating on extent noticed whether room was rotating, head rotation, torso rotation, *Kennedy SSQ*.
Findings:	(1)	Rotation of head or torso had a significant positive association with presence.
	(2)	Ratings on the extent of noticing room rotation had a significant negative association with presence.
	(3)	Saw_back_wall occurrence had a significant negative association with presence.
	(4)	Masters students reported significantly more presence than PhD and undergraduate students.
	(5)	*Turning method had no significant relationship with Saw_back_wall occurrence, although the variance for RWP was significantly lower.*
	(6)	*Turning method had no significant relationship with SSQ scores.*

[Regenbrecht 1998] Regenbrecht, H. T., Schubert, T. W., and Friedman, F. (1998). Measuring the sense of presence and its relations to fear of heights in virtual environments. *International Journal of Human-Computer Interaction, 10* (3), 233–249. See also Regenbrecht, H. T., and Schubert, T. W. (1997). *Measuring presence in virtual environments.* Paper presented at the 7th International Conference on Human-Computer Interaction, San Francisco, CA, August.

Computing platform:		Super Graphics Workstation.
Visual display:		Monoscopic, color Virtual Reality VR4 HMD. Subject standing on wooden platform that provided an unrestricted interaction space ~ 4 m in diameter.
Tracking:		Polhemus tracking devices.
Object manipulation:		None.
Virtual world:		Virtual world with a virtual cliff approximately 8 m high achieved by lowering parts of the ground. Depth cues provided using linear perspective enhancing lines at edges, special face coloring, and some architectural elements as a reference frame. No texture mapping, no advanced lighting.
Training:		2 min spent in virtual world before part of the ground was lowered to form a chasm and cliffs.
Experimental task:		Search for some texts in the virtual world and obey instructions given by these texts. These instructions required a subject to move around the virtual world. All tasks were completed if an exit sign was found. 20-min time limit.
Participants:		37 students and university employees; 23 males; age range 20 to 46; mean age 27 years. Little or no prior experience with VEs. Nonphobic.
Presence measures:		Questionnaire.
Person-related meas.:		*Fear of heights and avoidance behavior questionnaire*.
Task-related measures:		20-item State-Trait Anxiety Index.
Findings:	(1)	Presence and fear of heights were associated with significantly higher reports of fear.
	(2)	*Avoidance behavior had a significant negative association with experienced fear.*

[Riecke 2005] Riecke, B. E., Schulte-Pelkum, J., Caniard, F., and Bülthof, H. H. (2005). Influence of auditory cues on the visually induced self-motion illusion (circular vection) in virtual reality. *Proceedings of the 8th International Workshop on Presence*, London, UK, September, 49–57.

Factors:	Auditory cues (spatialized sound, mono sound, no sound).
Visual display:	Rotating curved projection screen with 54º × 45º FOV.
Auditory display:	Active noise-canceling Sennheiser HMEC300 headphones. Generated using generic HRTF and Lake DSP system with multiscape rendering.
Tracking:	None.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Photorealistic view of marketplace in Tübingen, Germany, with sounds of fountain (depending on condition).
Experimental task:	48 trials.
Participants:	20 participants; 8 males.
Study design:	Within-subjects.
Presence measures:	IPQ.
Task-related measures:	*Force feedback joystick to indicate onset of vection*, *vection intensity*, *vection buildup time*; *convincingness rating*.
Findings: (1)	Participants gave significantly higher presence scores for spatialized sound as compared with mono sound and no sound.
(2)	*Participants gave significantly increased convincingness ratings and vection buildup time value for spatialized sound.*

[Riecke 2004a] Riecke, B. E., Schulte-Pelkum, J., Avraamides, M. N., and Bülthoff, H. H. (2004a). Enhancing the visually induced self-motion illusion (vection) under natural viewing conditions in virtual reality. *Proceedings of the 7th Annual International Workshop on Presence,* Valencia, Spain, October, 125–132.

Factors:	Foreground markings (present, absent), rotation velocity (20°/s, 40°/s), rotation direction (left, right).
Visual display:	Curved projection screens, one with subtle scratches and markings at upper left to modify the surface and reflection properties. JVC D-ILA DLA-SX21S projector with 1400 × 1050 resolution, corrected for curvature.
Audio display:	Sennheiser HMEC300 active noise-canceling headphones.
Tracking:	None.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Tübingen, Germany, marketplace scene rotated around vertical axis with constant acceleration for 3 sec, maximum duration of constant velocity rotation 60 sec.
Training:	Familiarization vection stimulus and practice block of 4 trials.
Experimental task:	Participant instructed to pull a force-feedback joystick in the direction of perceived self-motion as soon as it was sensed. 4 repetitions of 2 different rotation velocities, presented in random order, and 2 turning directions presented in alternating order. 16 trials. Participant seated, yielding 54° × 40.5° FOV.
Participants:	22 participants.
Study design:	Between-subjects for foreground marking, within-subjects for rotation velocity and rotation direction.
Presence measures:	IPQ.
Person-related meas.:	Presence susceptibility questionnaire, Kennedy SSQ.
Task-related measures:	Vection onsest time, vection intensity, convincingness of vection rating, *50% vection onset time, time between vection onset and maximum vection*.

Findings: (1) Total IPQ scores and all subscales had a significant positive correlation with convincingness rating.

(2) The IPQ Involvement/Attention subscale had a significant negative correlation with vection onset time. Presence scores had no significant correlation with vection intensity.

(3) Foreground markings and rotation velocity had a significant relationship with vection onset time, vection intensity, 50% vection onset time, time between vection onset and maximum vection, convincingness of vection, with increased vection results for the foreground markings and faster rotation velocity.

[Riecke 2004b] Riecke, B. E., J. Schulte-Pelkum, M.N. Avraamides, M. von der Heyde, and Bülthoff, H. H. (2004). The effect of cognition on the visually-induced illusion of self-motion (vection). *Journal of Vision, 4* (8), 891a. Available: http://www.kyb.mpg.de/publications/pdfs/pdf2538.pdf

Factors: Visual stimulus (natural scene, mosaic-like scrambling, random slices).
Visual display: Curved projection screen, with FOV 54° × 40.5°.
Tracking: None.
Navigation: None.
Object manipulation: None.
Virtual world: Photorealistic representation of Tübingen, Germany, marketplace.
Experimental task: Observe rotating scene and report any experience of vection.
Participants: 12 participants.
Study design: Within-subjects.
Presence measures: IPQ.
Task-related measures: *Vection onset time*, *vection intensity*, *vection convincingness rating*.
Findings: (1) Natural scene was associated with significantly higher presence scores than mosaic-like scrambling and random slices.

(2) Natural scene was associated with significantly increased vection as measured by vection onset time, vection intensity, and convincingness ratings.

[Riley 2001] Riley, J. M. (2001). *The utility of measures of attention and situation awareness for quantifying telepresence*. Doctoral dissertation, Mississippi State University, MS.

Factors: Task complexity (low mine density, moderate mine density, high mine density).
Computing platform: Intergraph TDZ 2000 GXI workstation with high-performance graphics subsystems and a Dell PC.
Visual display: Two 21-in. graphics monitors operating under frame interlaced stereo mode at 1280 × 1024 resolution, viewed using CrystalEyes stereographic goggles.
Navigation: Standard mouse used to navigate a simulated robotic vehicle.
Object manipulation: Keyboard used to give commands to robotic vehicle.
Virtual world: Audio cues used to present a ringing bell sound whenever part of the robot was directly over a landmine and an auditory signal to mark collisions with objects.
Training: First training period provided instruction on how to operate the simulated robotic vehicle for teleoperation tasks using the mouse controller and how to manipulate the robotic arm using keyboard and voice commands. Included instruction, demonstration, and hands-on practice. Second training period provided instruction, demonstration, and hands-on practice using the keyboard for completing secondary monitoring tasks and also provided practice of both tasks performed simultaneously. Third training session provided explanation of Situation Awareness Global Assessment Technique (SAGAT) queries and survey administration during trials, with practice including multitask performance involving SAGAT freezes and queries. Total time 2 hrs.
Experimental task: Primary task: operate a robotic vehicle (via voice commands) to locate, uncover, identify, and neutralize 4 landmines. Secondary tasks: monitor displays for visual

		signals indicating a critical event associated with the rover and controls in the teleoperation task (one given in VE and other in RE). 30 to 50 min. Two trials.
Participants:		24 university students; 22 males; age range 19 to 26; mean age 20.25 years. PC and video game experience.
Study design:		Between-subjects.
Presence measures:		19-item subset of Witmer-Singer PQ.
Person-related meas.:		18-item subset of Witmer-Singer ITQ.
Task-related measures:		Modified Cooper-Harper perceived workload scale, SAGAT queries for average situation awareness, hit-to-signal ratios for attention to each monitoring task, and comparison of ratios across monitoring environments.
Performance measures:		Average time-to-mine neutralization.
Findings:	(1)	Participants in the higher complexity (low mine density) condition reported significantly less presence than those in the lower complexity conditions.
	(2)	Presence had no significant relationship with average situation awareness or the ratio of attention scores across VE and RE.
	(3)	Presence had a significant negative correlation with average time-to-mine neutralization, perceived workload, and hit-to-signal ratio in VE.
	(4)	Presence had a significant positive correlation with ITQ.
	(5)	*Task complexity had a significant negative relationship with performance.*
	(6)	*Task performance had a significant negative correlation with perceived workload, average situation awareness, and hit-to-signal ratio in VE.*
	(7)	*Average situation awareness had a significant positive correlation with perceived workload, the ratio of attention across the VE and RE, and hit-to-signal ratio in VE.*
	(8)	*Task complexity had no significant relationship with situation awareness, attention, or workload.*

[Riley 1999] Riley, J. M., and Kaber, D. B. (1999). The effects of visual display type and navigational aid on performance, presence, and workload in virtual reality training of telerover navigation. *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting*. Houston, USA, September–October, 1251–1255.

Factors:		Visual display (HMD, projection screen, monitor), navigational aid (written directions, plan-view layout).
Visual display:		HMD with 640×480 resolution, large projection screen with 600×800 resolution, computer monitor with 1280×1024 resolution.
Navigation:		Using standard mouse.
Object manipulation:		None.
Experimental task:		Navigate a simulated telerobotic vehicle through an office environment consisting of 9 rooms and 3 independent paths. 2 trials.
Participants:		24 participants; age range 20 to 42.
Study design:		Between-subjects for display type, within-subjects for navigational aid.
Presence measures:		Witmer-Singer PQ.
Person-related meas.:		Witmer-Singer ITQ, Manikin Test, Carter and Wolstad spatial ability test.
Task-related measures:		National Aeronautics and Space Administration (NASA) Task Load Index (TLX).
Performance measures:		Task completion time, route selection.
Findings:	(1)	Monitor participants gave significantly higher presence scores.
	(2)	Presence significantly increased over the two trials.
	(3)	ITQ had a significant positive correlation with presence.
	(4)	Workload had a significant negative correlation with presence.
	(5)	Spatial ability had a significant correlation with presence but not with task performance or workload.
	(6)	*Visual display had no significant relationship with performance or workload.*
	(7)	*Map usage was associated with significantly improved performance in both navigation time and selection of most efficient route.*

(8) Map usage was associated with significantly lower ratings of perceived workload.
(9) Trial order had a significant effect on presence, with participants reporting more presence during the second trial.

[Robillard 2003] Robillard, G., Bouchard, S., Fournier, T., and Renaud, P. (2003). Anxiety and presence during VR immersion: A comparative study of the reactions of phobic and non-phobic participants in therapeutic virtual environments derived from computer games. *CyberPsychology & Behavior, 6* (5), 467–476.

Factor:	Participant phobia (present, absent).
Computing platform:	Pentium III PC with ATI Technologies, Inc. Radeon graphics card.
Visual display:	i-O Displays I-Glass HMD, with 480 × 640 resolution, draped with black cloth to eliminate ambient light.
Audio display:	PC stereo speakers.
Tracking:	Intertrax head tracker.
Navigation:	Sidewinder game pad.
Virtual world:	Modified computer game environments: arachnophobia world based on Half-Life, acrophobia and claustrophobia worlds based on Unreal Tournament.
Training:	Exposure to neutral, non-phobic virtual world to gain familiarity with controls.
Experimental task:	Phobic participants had three sessions of exposure to appropriate phobic virtual world, where participant was encouraged to approach phobic stimuli as closely as possible. 20-min exposure for each session. Nonphobic participants had two 5-min sessions in same virtual world as that of matched phobic participant. Data reported here from first session only.
Participants:	13 participants with diagnosed phobias; 4 males; age range 18 to 60; mean age 33.7 years. 13 nonphobic participants; age and gender matched with phobic participants. Prospective participants screened using the Structured Clinical Interview for DSM-IV, Geer's Fear Survey Schedule II, Spielberger's State-Trait Anxiety Inventory (Form Y), Beck Depression Inventory.
Study design:	Between-subjects.
Presence measures:	French version of Witmer-Singer PQ, with unscored items omitted and using restructured subscales: Realism, Affordance to Act, Interface Quality, Affordance to Examine, Self-Evaluation of Performance. Verbal rating of presence queried every 5 min during exposure.
Person-related meas.:	French version of Witmer-Singer ITQ, with unscored items omitted and restructured subscales: Focus, Involvement, Emotion, Play.
Task-related measures:	Verbal rating of perceived realism, *Kennedy SSQ*. (Verbal rating of anxiety and simulator sickness queried every 5 min during exposure.)

Findings:

(1) Participant phobia had a significant relationship with presence assessed using the PQ Total and PQ Realism and verbal rating of presence, with phobic participants reporting higher levels of presence and realism.
(2) ITQ Total and Emotions subscale had a significant positive correlation with verbal ratings of presence.
(3) PQ Total, and Realism and Affordance to examine subscales had a significant positive correlation with verbal ratings of presence.
(4) Verbal rating of perceived realism and mean verbal anxiety had a significant positive correlation with verbal ratings of presence.
(5) Participant phobia had no significant relationship with SSQ Total and subscale scores.
(6) Participant phobia had no significant relationship with verbal rating of perceived realism.

[Romano 1998] Romano, D. M., Brna, P., and Self, J. A. (1998). *Collaborative decision making and presence in shared dynamic virtual environments.* Paper presented at the Presence in Shared Virtual Environments' Workshop, British Telecom Laboratories, Ipswich, UK, June. See also Romano, D. M., and Brna, P. (2001). Presence and reflection in training: Support for learning to improve quality decision-making skills under time limitations. *CyberPsychology and Behavior, 4* (2), 265–278.

Factors:		Collaboration (playing game as a team of two, individually).
Computing platform:		2 multimedia PCs.
Visual display:		Two 15-in. desktop monitors.
Navigation:		Combination of standard 2 DOF mouse and arrow keys.
Object manipulation:		Combination of standard 2 DOF mouse and arrow keys.
Virtual world:		Multiparticipant virtual game where virtual world had constraints similar to reality (e.g., participant had to breathe while swimming and died if shot by hostile creatures). Limited number of lives. Self-representation as gun.
Training:		Preliminary training on basic game features for those who had no prior experience.
Experimental task:		Find way out of maze while surviving the attack of other humans and animals.
Participants:		6 pairs of participants; 5 males; age range mid-20s to mid-30s. Participants knew their partners prior to the study.
Study design:		Within-subjects.
Presence measures:		3-item presence questionnaire, 6-item co-presence questionnaires.
Person-related meas.:		Game playing experience.
Task-related measures:		Self-rating of collaboration and performance.
Findings:	(1)	Play game as team of two was associated with significantly higher co-presence scores.
	(2)	Self-rating of performance had a positive correlation with presence.
	(3)	Game experience had a positive relationship with presence.

[Sabourin 2004.] Sabourin, C., and Bouchard, S. (2004). The impact of instructions on the feeling of presence during virtual immersions. *Cyberpsychology & Behavior, 7* (3), 306.

Factors:		Instructions (minimal, minimal and context, minimal and suggestions, all).
Computing platform:		Pentium IV PC with STI Radeon 64 video card.
Visual display:		I-Glass HMD with 640 × 480 resolution.
Tracking:		Intertrax motion tracker for head tracking.
Navigation:		Joystick.
Virtual world:		Temple of Horus taken from *Unreal Tournament: Game of the Year*, modified to remove violent content.
Training:		Immersion in a neutral/irrelevant virtual world to learn how to navigate and the concept of presence.
Experimental task:		Minimal instructions were to visit the Temple of Horus by following candles lit to guide the way. Minimal instructions and context added a description of the Egyptian god Horus and the history of the temple. Minimal instructions and explicit suggestions about senses stimulated during immersion added statements such as "It's really cold down here."
Participants:		48 participants; 24 males; age range 19 to 52.
Study design:		Between-subjects.
Presence measures:		Witmer-Singer PQ, rating. Both taken after initial immersion in neutral virtual world and after immersion in experimental conditions.
Person-related meas.:		Witmer-Singer ITQ.
Task-related measures:		*Realism rating*. Used in same manner as presence measures.
Findings:	(1)	Presence ratings for the experimental conditions were significantly higher than those given for neutral virtual world but did not differ significantly across experimental conditions.

(2) PQ scores for the experimental conditions were not significantly different from those given for neutral virtual world and did not differ significantly across experimental conditions.

(3) Realism ratings for the experimental conditions were not significantly different from those given for neutral virtual world. Instructions with suggestions were associated with significantly higher realism ratings than other types of instruction.

[Sacau 2005] Sacau, A., Laarni, J., Ravaja, N., and Hartmann, T. (2005). The impact of personality factors on the experience of spatial presence. *Proceedings of the 8th International Workshop on Presence*, London, UK, September, 143–151.

Factors:	FOV (60º, 30º).
Computing platform:	PC, game based on the *Doom 3* 3D engine.
Visual display:	Projection screen.
Auditory display:	High-quality headphones.
Tracking:	None.
Navigation:	Standard mouse.
Object manipulation:	None.
Virtual world:	Game using Mayan temple consisting of 17 rooms on 3 floors.
Experimental task:	Search for gold bars.
Participants:	Overall study looking at different media: 240 undergraduates and graduates; 102 males; age range 18 to 41; mean age 24.25 years. For VE element: 80 participants; 27 males.
Study design:	Between-subjects.
Presence measures:	MEC-SP Self Location, Possible Actions subscales and Domain-Specific Interest, Spatial Visual Imagery, Absorption trait variables.
Person-related meas.:	NEO Five-Factor Inventory (NEO-FFI) personality factors scales.
Findings: (1)	FOV had no significant relationship with spatial presence.
(2)	Participants with low Domain-Specific Interest reported significantly less spatial presence than participants with medium levels of Domain-Specific Interest.
(3)	Using data from overall study: Spatial presence had a significant positive correlation with Domain-Specific Interest, Absorption, Agreeableness.
(4)	Using data from overall study: NEO-FFI Extraversion had a significant positive correlation with Spatial Visual Imagery. Neuroticism and Openness had a significant positive correlation with Absorption. Conscientiousness had a significant positive correlation with Domain-Specific Interest.

[Sacau 2004] Sacau, A., and Coutinho, S. (2004). Presence in educational and entertaining virtual environments. *Proceedings of the 7th Annual International Workshop on Presence,* Valencia, Spain, October, 325–331.

Factors:	Content (educational, entertainment).
Computing platform:	Compaq Presario 2500, Intel Pentium IV.
Visual display:	Desktop monitor.
Auditory display:	Sony MDR-P180 headphones for entertainment environment.
Navigation:	Logitech wireless mouse for educational environment, standard keyboard for entertainment environment.
Object manipulation:	None.
Virtual world:	Education world was the interactive Mozart's Museum developed by MEC Project, with 4 floors providing information about Mozart's life and compositions and containing interactive objects such as a violin and harpsichord that played music. Entertainment world was the Lara Croft's home training area selected from *Tomb Raider III*. This was a noninteractive environment, 2 floors with 3 or 4 rooms on each. Playing level was not used to try to prevent participants from "dying."

Experimental task: Explore VE.
Participants: 60 undergraduates; 30 males; age range 17 to 31; mean age 22 years. Computer engineering students, regular players of video games, those who had played *Tomb Raider* games were excluded.
Study design: Between-subjects.
Presence measures: 20-item Global Presence questionnaire, with 9-item Absorption subscale (based on Lombard and Ditton), 9-item Significance subscale (based on Dillon, Freeman and Avons, and others), 2-item direct Presence subscale (based on SUS Questionnaire).
Findings:
(1) Participants in the educational environment gave significantly higher Global Presence and Absorption scores.
(2) Content had no significant relationship with Direct Presence. There was a significant interaction with gender, such that, for the entertainment environment, females reported significantly higher Direct Presence.
(3) Absorption and Significance had a positive correlation with Global Presence.
(4) Age had no significant association with Global Presence.

[Sallnäs 2004 (3)] Sallnäs, E.-L. (2004). *The effect of modality on social presence, presence and performance in collaborative virtual environments*. Doctoral thesis, Kungliga Tekniska Högskolan (KTH) (Royal Institute of Technology), Stockholm, Sweden.

Factors: Modality (video conference, voice, text-chat).
Computing platform: Two PowerBook PCs networked via Ethernet. System developed in Active Worlds. In text-chat condition, communication provided using Active Worlds.
Visual display: Two 21-in. desktop monitors.
Audio display: Telephones with headsets.
Virtual world: Picture exhibition with information points that included posters and QuickTime movie clips with audio. Self-representation by human-like avatars.
Experimental task: Decision-making task.
Participants: 80 participants (split between this and another follow-up experiment), working in pairs.
Study design: Between-groups.
Presence measures: Presence questionnaire, social presence questionnaire.
Task-related measures: 14-item perceived task performance questionnaire, frequency of words spoken, frequency of words spoken/sec.
Performance measure: *Time to complete task.*
Findings:
(1) Participants who used using text-chat reported significantly less presence and less social presence.
(2) Participants who used text-chat took significantly longer to complete the task and dialogues were significantly scarcer and words/second were significantly lower.

[Sallnäs 2004 (4)] Sallnäs, E.-L. (2004). *The effect of modality on social presence, presence and performance in collaborative virtual environments*. Doctoral thesis, Kungliga Tekniska Högskolan (KTH) (Royal Institute of Technology), Stockholm, Sweden.

Factors: Modality (VE video conference, VE voice, Web video, Web audio).
Computing platform…
Performance measures: As in [Sallnäs 2004 (3)] with the addition of a comparable Web environment condition.
Findings:
(1) Virtual or Web modality had no significant relationship with presence or social presence. A significant interaction with video/audio was found, such that participants in the Web video condition reporting more presence than those in the Web audio condition.
(2) Participants who communicated using text-chat reported significantly less social presence.

(3) Virtual or Web modality had no significant relationship with task completion time but those in the virtual video condition used a substantially lower word rate.

(4) Participants in the 2 VE conditions took significantly longer than those in the audio conditions.

[Sallnäs 2004 (6)] Sallnäs, E.-L. (2004). *The effect of modality on social presence, presence and performance in collaborative virtual environments*. Doctoral thesis, Kungliga Tekniska Högskolan (KTH) (Royal Institute of Technology), Stockholm, Sweden.

Factors:	Haptic force feedback (delivered to fingertip, none).
Computing platform:	Software implemented using Reachin Technologies Application Programming Interface (API) on a Windows 2000 PC.
Visual display:	Two desktop monitors.
Audio display:	None.
Haptic display:	Two SensAble Technologies PHANTOM devices.
Navigation:	Using haptic display.
Object manipulation:	Using haptic display. When no haptic feedback is provided, PHANTOM operates as a 3D mouse.
Virtual world:	Room with 2 large shelves with 6 cubes resting on them and 2 small target shelves.
Experimental task:	Working alternatively, lift a cube and pass it to partner who tapped other shelf with the cube. Partner then returns cube to originator, who taps shelf with the cube. Task difficulty adjusted by randomly varying cube size.
Participants:	18 participants, working in pairs.
Presence measures:	Witmer-Singer PQ, 34-item social presence questionnaire.
Task-related measures:	14-item perceived task performance questionnaire.
Findings:	(1) Participants gave significantly higher presence and social presence scores for use of force feedback.
	(2) Perceived performance had a significant correlation with presence but had no correlation with social presence.
	(3) Use of force feedback was associated with significantly higher assessments of perceived performance.

[Sallnäs 2000] Sallnäs, E.-L., Rassmus-Gröhn, R., and Sjoström, C. (2000). Supporting presence in collaborative environments by haptic force feedback. *ACM Trans. on Computer-Human Interaction, 7* (4), 461–476. See also Sallnäs, E.-L. (1999). *Presence in multimodal interfaces.* Paper presented at the *2nd International Workshop on Presence*, University of Essex, Colchester, UK, April 1999. Also available: http://www.nada.kth.se/~evalotta/Presence/IWVP.html

Factors:	Haptic force feedback (delivered to fingertip, none).
Computing platform:	Intergraph workstation. Software developed using GHOST Software Development Kit.
Visual display:	Two 21-in. desktop monitors.
Audio display:	GN Netcom audio headsets using a telephone connection.
Haptic display:	Two SensAble Technologies PHANTOM devices (an “A” and a “T” model).
Navigation:	Using haptic display.
Object manipulation:	Using haptic display, one participant pushes cubes along the floor or lifts a cube by pressing it against a wall and pushing it up or participants work together in lifting a cube. When no haptic feedback is provided, PHANTOM operates as a 3D mouse.
Virtual world:	Room containing 8 cubes with simulated form, mass, damping and surface friction. A slight vibration distinguished between touching a cube and touching or holding onto a partner. Force feedback also provided for walls and partner. Self-representation as colored sphere 12 mm in diameter.
Training:	Approximately 2 min learning the interface.

Experimental task:	Five collaborative tasks. Four tasks require building patterns with cubes; other requires navigating through a constructed pattern.
Participants:	14 pairs of university students; 14 males; age range 20 to 31; mean 23 years. No prior experience with collaborative desktop virtual interfaces.
Study design:	Between-groups.
Presence measures:	32-item Witmer-Singer PQ Version 2.0, 8-item social presence questionnaire.
Task-related measures:	*14-item perceived performance questionnaire*.
Performance measures:	*Time to complete task*.
Findings: (1)	Participants reported significantly more presence for use of force feedback.
(2)	Haptic force feedback had no significant relationship with social presence.
(3)	*Participants using force feedback gave significantly higher assessments of perceived task performance.*
(4)	*Use of force feedback was related to significantly faster task completion times.*

[Sanders 2002] Sanders, R. D., and Scorgie, M. A. (2002). *The effect of sound delivery methods on a user's sense of presence in a virtual environment*. Master's thesis, Naval Postgraduate School, Monterey, CA.

Factors:	Audio delivery (5 speakers and subwoofer, headphones and subwoofer, headphones, no sound).
Computing platform:	Alienware computer with Creative Labs Audigy sound card, NVIDIA GeForce3 graphics card. Physiological data capture and analysis using Thought Technology's BioGraph software and ProComp.
Audio display:	Sennheiser HD570 headphones, 5 Genelec 1031A active speakers and 1 Genelec 1094A active 400 W subwoofer system.
Virtual world:	Medal of Honor: Allied Assault computer game, Omaha Beach Landing of the Normandy Invasion scenario. 10 min allowed.
Training:	Playing game, follow directions of 'drill instructor' and complete the Basic Training scenario.
Experimental task:	Starting from a position on the beach shingle, clear out the bunkers defending the beach.
Participants:	80 participants; 76 males.
Study design:	Between-subjects.
Presence measures:	6-item SUS Questionnaire, Witmer-Singer PQ, Δheart rate, Δskin conductance, Δskin temperature.
Person-related meas.:	Age, gender, game experience, caffeine, sleep.
Task-related measures:	Witmer-Singer ITQ.
Findings: (1)	Audio delivery had a significant relationship with PQ and SUS Questionnaire scores, with all sound conditions resulting in more presence than no sound. Type of delivery had no effect.
(2)	Audio delivery had a significant relationship with temperature, with a large decrease in temperature for any sound condition, compared to no sound, and for speakers and any headphone condition. There was no significant relationship with either heart rate or electrodermal activity.
(3)	PQ scores had a significant positive correlation with SUS Questionnaire scores.
(4)	PQ scores had a significant positive correlation with ITQ scores.
(5)	PQ scores had a significant positive correlation with electrodermal activity and heart rate but not with temperature.
(6)	SUS Questionnaire scores had a significant positive correlation with electrodermal activity but not with changes in heart rate or temperature.
(7)	Game experience had a significant positive correlation with PQ scores. Caffeine had a significant positive correlation with PQ scores ($p < 0.10$). Age, gender, and sleep had no significant relationship.

[Sas 2003a] Sas, C., and O'Hare, G. (2003a). Impact of cognitive style upon sense of presence. *Proceedings of the 10th International Conference on Human Computer Interaction*, Heraklion, Crete, Greece, June, 696–700. See also Sas, C., O'Hare, G. M. P., and Reilly, R. (2004). Presence and task performance: An approach in the light of cognitive style. *Cognition, Technology and Work, 6* (1), 53–56.

Factors:		Cognitive style.
VE System:		Nonimmersive ECHOES system.
Virtual world:		Multistory building, where levels containing several furnished rooms are connected by virtual elevators. Each room supports a cohesive set of functions.
Training:		Gain familiarity with the environment and learn movement controls.
Experimental task:		Exploration task followed by search task where participants were asked to find a valuable painting hidden in the building. Approximately 25 min.
Participants:		30 undergraduate and postgraduate students; 18 males; age range 20 to 38.
Presence measures:		Questionnaire.
Person-related meas.:		Myers-Briggs Type indicator.
Task-related measures:		Number of navigation collisions.
Performance measures:		Time to complete search.
Findings:	(1)	Participants classified as more Feeling or more Sensitive gave significantly higher presence scores.
	(2)	Time to complete the task had a significant positive correlation with presence.
	(3)	Number of collisions had a significant positive correlation with presence.

[Sas 2003b] Sas, C., and O'Hare, G. (2003b). The presence equation: An investigation into cognitive factors underlying presence. *Presence, 12* (5), 523–537.

Factors:		Cognitive style (absorption, creative imagination, empathy, cognitive type), gender.
Virtual world:		The EduCational Hypermedia On-LinE System (ECHOES) training environment for maintenance of complex industrial artifacts. Provides a virtual 4-story building, with numerous rooms on each floor, including a conference room, lobby room, training room, and elevator. Specific user activities are associated with each room.
Training:		Exploratory task to gain familiarity with the environment and navigation control. 25-min time limit.
Experimental task:		Search tasks including finding a hidden painting and finding the library and specific information within the library given spatial landmarks.
Participants:		15 undergraduate and postgraduate students; 9 males; age range 20 to 38.
Study design:		Within-subjects.
Presence measures:		Questionnaire, SUS questionnaire.
Person-related meas.:		TAS, Creative Imagination Scale (CIS), Davis' Interpersonal Reactivity Index (IRI), Myers-Briggs Type Indicator (MBTI), gender.
Findings:	(1)	Creative imagination score and interpersonal reactivity index had a significant positive correlation with presence. Absorption and cognitive type had no significant correlation with presence.
	(2)	Gender had no significant association with presence, absorption, or creative imagination but had a significant interaction with empathy, such that increased empathy was reported for females.
	(3)	Presence score had a significant positive correlation with SUS questionnaire score.

[Schneider 2004] Schneider, E. F., Lang, A., Shin, M., and Bradley, S. D. (2004). Death with a story: How story impacts emotional, motivational, and physiological responses to first-person shooter video games. *Human Communication Research*, *30* (3), 361–375.

Factors:		Game content (story line provided, no story line), game content (2).

Visual display: Desktop monitor.
Virtual world: Games with a story line were *Outlaws* and *Half-Life*. Games with no story line were *Doom 2* and *Quake 2*.
Experimental task: Play 4 different games for 8 min each. Participants allowed to configure, name, and customize their character.
Participants: 30 undergraduates; 24 males. All experienced game players enrolled in a video game course.
Study design: Within-subjects.
Presence measures: 3-item verbal scale, 9-point pictorial Self-Assessment Manikin (SAM) presence scale.
Task-related measures: *4-item identification with protagonist scale*, *2-item identification with goal of overcoming opponent scale*, *2-item identification with general goals of protagonist scale*, *self-reported emotional experience scale*, *Δskin conductance as an indicator of physiological nervous system activation*.
Findings:
(1) Participants gave significantly higher presence scores for the verbal scale and SAM for games with a story line.
(2) Participants gave significantly higher scores on each identification scale for games with a story line.
(3) Participants gave significantly higher emotional experience scores for games with a story line.
(4) Participants' level of arousal remained higher significantly longer for games with a story line.

[Schroeder 2001] Schroeder, R., Steed, A., Axelsson, A.-S., Heldal, I., Abelin, Å., Wideström, J., Nilsson, A., and Slater, M. (2001). Collaborating in networked immersive spaces: As good as being together? *Computers & Graphics, 25,* 781–788.

Factors: Visual display (1 participant in each of two 5-sided Caves, 1 participant in 5-sided Cave and 1 participant using desktop, real world).
Computing platform: SGI Onyx2 InfiniteReality with fourteen 250-MHz MIPS R10000 processors, 2 GB RAM, 3 InfiniteReality graphics pipes. SGI Onyx2 with eight 300-MHz R12000 MIPS processors, 8 GB RAM, 4 InfiniteReality graphics pipes. SGI O2 with 1 MIPS R1000 processor, 256 MB RAM. DIVE toolkit, DIVEBONE connection, and dVise 6.0 software with SGI Performer renderer. Network lag ~ 180 ms between Onyx 2 systems; less between the first and third systems.
Visual display: 3 × 3 × 3 m TAN VR-CUBE with projection on 5 walls (no ceiling), stereoscopic viewing using StereoGraphics Corporation CrystalEyes shutter glasses; rendering performance at least 30 Hz. Trimension ReaCTor with projections on 3 × 2.2 m walls and 3 × 3 m floor, stereoscopic viewing CrystalEyes shutter glasses; rendering performance 45 Hz. 19-in. monitor; rendering performance at least 20 Hz.
Audio display: Robust Audio Toolkit for communication between participants, except on one occasion when 2 mobile phones were used.
Tracking: Polhemus tracking of both shutter glasses and hand for VR-CUBE, InterSense IS-900 system tracking for shutter glasses and interaction device for ReaCTor.
Navigation: Using 3D wand with VR-CUBE system, interaction device with 4 buttons, and analogue joystick with Trimension ReaCTor system (locomotion enabled) by moving middle button on a standard 3-button mouse with desktop system.
Object manipulation: Select objects by putting virtual hand into a virtual cube and press/release wand/joystick button to move object or by using standard mouse buttons.
Virtual world: Participant represented to partner as a simple human-like male avatar with jointed arm; self-representation as virtual hand.
Experimental task: Two participants cooperate to solve a puzzle by arranging eight 30-cm^3 colored blocks into a cube, such that each side of the completed cube displays a single color. 20-min time limit.
Participants: 66 pairs of participants.

Study design: Between-groups.
Presence measures: 2-item presence questionnaire, 1-item place-to-visit rating.
Task-related measures: *3 items on collaboration, 3 items on contribution to task questionnaire.*
Performance measures: *Time to complete task.*
Findings:
(1) Cave participants gave significantly higher presence scores. No significant difference between Cave systems.
(2) Cave participants gave significantly higher place-to-visit ratings. No significant difference between Cave systems. Cave participants whose partner was also immersed reported significantly more presence than those whose partner used the desktop system.
(3) 5-sided Cave participants gave significantly higher co-presence scores than desktop participants. Participants who were both immersed reported significantly higher presence than the immersed participant (5-sided Cave) with desktop partner.
(4) Environment type (real and 2 participants using projection displays) had no significant relationship with time to complete task.
(5) Visual display had no significant relationship with rating of collaboration.
(6) Visual display had a significant relationship with rating of contribution, such that immersive participants were rated as more active than desktop participants but had no significant difference in amount of verbal communication.

[Schubert 2000 (1)] Schubert, T., Regenbrecht, H., and Friedmann, F. (2000). Real and illusory interaction enhance presence in virtual environments. *Proceedings of the 3rd International Workshop on Presence,* Delft University of Technology, The Netherlands, March. See also Regenbrecht, H., and Schubert, T. (2002). Real and illusory interactions enhance presence in virtual environments. *Presence: Teleoperators & Virtual Environments, 11* (4), 425–434.

Factors: Type of movement (self-movement, preset), agents (present, absent).
Computing platform: SGI workstation.
Visual display: Virtual Research VR4 HMD. Update rate ~ 15 Hz. In preset movement condition, a pre-recorded, film-like presentation showing the VE from the viewpoint of a person slowly wandering and looking around was presented on the HMD. Participant standing.
Tracking: Polhemus FASTRAK for head tracking in self-movement condition.
Navigation: When viewpoint was under participant control, participant could change viewpoint by turning his head and/or walking around in a circle 5 m in diameter. In other condition, participant had no control of navigation.
Object manipulation: None.
Virtual world: Hallway representing an administration building. Participant stands at an intersection, looking into 4 corridors with numerous doors. Across the wall, several plates are visible. Circle boundary marked with red line. In the agents' present condition, doors opened and closed from time to time and 2 comic-strip-like shoes came out of the doors, walked across the hall, and entered other rooms.
Training: Brief verbal description of the VE technology, especially the HMD, that the virtual world participants would experience.
Experimental task: Count number of plates on the wall. 5-min time limit.
Participants: 56 students and university staff members; 34 males; age range 19 to 61; mean age 29.3 years.
Study design: Between-subjects.
Presence measures: IPQ.
Findings:
(1) Self-movement participants gave significantly higher Spatial Presence and Realness.
(2) Agents had no significant relationship with any category of presence.

[Schubert 2000 (2)] Schubert, T., Regenbrecht, H., and Friedmann, F. (2000). Real and illusory interaction enhance presence in virtual environments. *Proceedings of the 3rd International Workshop on Presence,* Delft University of Technology, The Netherlands, March. See also Regenbrecht, H., and Schubert, T. (2002). Real and illusory interactions enhance presence in virtual environments. *Presence: Teleoperators & Virtual Environments, 11* (4), 425–434.

Factors:		Agent interaction (expected, not expected).
Computer platform:		SGI workstation.
Visual display:		Virtual Research VR4 HMD. Update rate ~ 15 Hz. Participant standing.
Tracking:		Polhemus FASTRAK for head tracking in self-movement condition.
Navigation:		Free movement in a circle 5 m in diameter.
Object manipulation:		None.
Virtual world:		As in [Schubert 2000 (1)].
Training:		Brief verbal description of the VE technology, especially the HMD, that the virtual world participants would experience. In addition, participants were told they would see other characters in the virtual world. Half the participants were told these characters would react to the participant's actions; the others were told no interactions were possible.
Experimental task:		Count number of plates on the wall. 5-min time limit.
Participants:		26 students; 4 males; age range 15 to 41; mean age 24.6 years.
Study design:		Between-subjects.
Presence measures:		IPQ.
Finding:	(1)	Expectation of agent interaction was associated with significantly higher Spatial Presence subscale scores.

[Schuemie 2005] Schuemie, M. J., Abel, B., van der Mast, C. A. P. G., Krijn, M., and Emmelkamp, P. M. G. (2005). The effect of locomotion technique on presence, fear and usability in a virtual environment. *Proceedings of Euromedia 2005*, Toulouse, France, April, 129–135.

Factors:		Navigation (walking-in-place, hand-controlled, gaze-directed).
Computing platform:		PC with 3D-Labs Oxygen G420 graphics card.
Visual display:		Visette Pro HMD with FOV 70º diagonal, resolution 640 × 480. Frame rate fixed at 15 fps.
Tracking:		Ascension Technology's Flock of Birds for head tracking.
Navigation:		Using walking-in-place, trackball, or head tracking.
Virtual world:		Room designed to determine controllability of interaction techniques with objects such as couches and plants. One spot marked with a flag which, when participant pressed button would disappear and reappear somewhere else. A separate area, representing the outside of a tall building, reached by an elevator, containing height situations designed to determine effect of locomotion on fear.
Training:		In separate training room for gain familiarity with interface.
Experimental task:		Navigate around objects to the flag (trying to avoid collisions), pressing button when reaching flag. Repeat, as flag moved to another six positions. Then take elevator and in new space locate boxes. At each box, look inside to determine what figure was inside.
Participants:		42 participants; 19 males; age range 18 to 60; mean age 30.4 years. 3 subjects unable to complete because of extreme fear.
Presence measures:		IPQ.
Person-related meas.:		Age, gender, AQ, Computer Experience (CE) questionnaire, TAS.
Task-related measures:		*SUD rating of fear, heart rate, head-down rotations, avoidance of edge of large drop, Kennedy SSQ, Usability questionnaire.*
Performance measures:		*Number of collisions, accuracy in positioning near flags*.
Findings:	(1)	Walking-in-place was associated with significantly higher presence scores.

(2) AQ scores, gender, computer experience, and TAS scores had no significant correlation with IPQ scores.
(3) Age had a significant positive correlation with IPQ scores.
(4) Walking-in-place was associated with significantly higher SUDS scores.
(5) Locomotion technique had no significant relationship with avoidance measure.
(6) Locomotion technique had a significant relationship with SSQ scores, with most symptoms reported for gaze directed and walking-in-place where head tracking used.
(7) Locomotion technique had no significant relationship with usability scores.
(8) Locomotion technique had no significant relationship with positioning accuracy but had a significant relationship with number of collisions, with walking-in-place participants showing more collisions.

[Seay 2001] Seay, A. F., Krum, D. M., Hodges, L., and Ribarsky, W. (2001). Simulator sickness and presence in a high FOV virtual environment. *Proceedings of the Conference on Human Factors in Computing Systems,* Minneapolis, USA, April, 784–785.

Factors:	FOV (180º, 60º), stereopsis (present, absent), interactivity (driver, passenger).
Computing platform:	Non-expensive Automatic Virtual Environment (NAVE).
Visual display:	3 8 × 6 ft screens, with sides positioned at 120º to center screen. Used in single-screen and three-screen configuration. User seated in front of center screen.
Navigation:	Using joystick.
Experimental task:	10 min.
Participants:	156 undergraduates, grouped into pairs; 133 males; age range 17 to 38.
Study design:	Within-subjects.
Presence measures:	Witmer-Singer PQ.
Person-related meas.:	Witmer-Singer ITQ.
Task-related measures:	Kennedy SSQ.

Findings:
(1) Participants gave significantly higher presence scores for 180º.
(2) Participants gave significantly higher presence scores for the driver role.
(3) ITQ and SSQ scores had no significant correlation with PQ scores or with each other. However, when experiment conditions were controlled, there was a significant positive correlation between PQ and ITQ scores.
(4) Participants reported significantly more SSQ Nausea symptoms for 180º. There was a significant interaction effect with Interactivity.
(5) FOV and Interactivity had a significant interaction for SSQ Occulomotor Discomfort and Disorientation subscale scores.

[Shim 2003] Shim, W., and Kim, G. J. (2003). Designing for presence and performance: The case of the virtual fish tank. *Presence, 12* (4), 374–386. See also Shim, W., and Kim, G. J. (2001). *Tuning of the level of presence*. Paper presented *the 4th Annual International Workshop on Presence*, Philadelphia, USA, May.

Factors:	Level of detail (high, low), FOV (180º, 150º, 120º).
Computing platform:	3 Pentium III PCs with NVIDIA Quadro-based graphic accelerator cards running Windows 2000. Software developed using Sense8's WorldToolKit.
Visual display:	3 desktop monitors; participant with fixed head position with viewing distance of 1 m.
Audio display:	None.
Tracking:	None.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Virtual fish tank containing 30 fish that exhibited different levels of behaviors.
Training:	None.
Experimental task:	Watch display for 90 sec for each (of 6) viewing combination(s).

Participants:		23 undergraduate students; 20 males; age range 19 to 27.
Study design:		Within-subjects.
Presence measures:		8-item version of Witmer-Singer PQ.
Person-related meas.:		4-item version of Witmer-Singer ITQ.
Findings:	(1)	High level of detail was associated with significantly higher presence scores.
	(2)	180º was associated with significantly higher presence scores.

[Singer 1998] Singer, M. J., Ehrlich, J. A., and Allen, R. C. (August 1998). *Effect of a body model on performance in a virtual environment search task* (ARI Technical Report 1087). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors:		Self-representation (body model, pointer).
Computing platform:		SGI Onyx, with Performer and in-house software.
Visual display:		Virtual Research VR4 HMD with 742 × 230 color pixels/eye, FOV 48º H × 36º V. Participant eye height used as basis to adjust display.
Tracking:		Ascension Technology’s Flock of Birds used for head, shoulder, feet, right arm, and right hand.
Object manipulation:		In-house manufactured hand-held wand with button used to make target disappear.
Virtual world:		12 different room configurations, rated as medium or low complexity. Typical office spaces and furniture. Three targets (briefcases) placed in each six-room trial set.
Training:		View videotape demonstrating moving and acquiring targets. Then guided through a locomotion and acquisition practice session in VE practice room.
Experimental task:		Search for briefcases hidden in office rooms. 6 trials.
Participants:		32 participants; 18 males; age range 18 to 44; mean age 22.5 years. Low scores on initial SSQ and averaged 8 hrs/week computer use. Four participants had prior VE experience.
Presence measures:		Witmer-Singer PQ.
Person-related meas.:		Witmer-Singer ITQ.
Performance measures:		*Number targets acquired, time to complete search, number of collisions. Also for each target room, time/collisions to visual acquisition of target, time/collisions to physical acquisition, time/collisions to exit.*
Findings:	(1)	Self-representation had no significant relationship with presence.
	(2)	*Self-representation had no significant relationship with the number of targets acquired or with any time/collision measures.*

[Singer 1997] Singer, M. J., Allen, R. C., McDonald, D. P., and Gildea, J. P. (February 1997). *Terrain appreciation in virtual environments: Spatial knowledge acquisition* (ARI Technical Report 1056). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors:	Level of equipment (Hi-VE with head tracking, and treadmill movement control; Low-VE with no head tracking and joystick movement control; standard map training). Level of detail (realistic, abstract terrain).
Computing platform:	SGI Onyx. In-house software.
Visual display:	VR4 HMD with 742 × 230 color pixels/eye, FOV 48º × 36º.
Tracking:	Isotracks for head and hand tracking. Polhemus sensor strapped over 1st knuckle of the index finger for pointing.
Navigation:	In the Hi-VE condition, using a treadmill where normal walking speeds were translated into a constant walking pace within the terrain database, movement in the direction of gaze. In the Low-VE condition, movement was controlled by Gravis 6 DOF joystick and pointing.
Object manipulation:	Pointing wand for indicating directions or locations and selecting objects.

Virtual world:	Two terrains: (1) Abstract terrain derived from composite topographical maps; (2) Terrain developed from topographical map and aerial photography of a 1-km area east of the McKenna Military Operations in Urban Terrain, Ft. Benning.
Training:	Topographical map training packet. Also, VE movement and control practiced using the VEPAB doorways and fixed tracking tasks, see [Singer 1995].
Experimental task:	Participants briefed on the terrain and path to be followed. While navigating terrain, at each of 3 checkpoints, participants locate several previously studied landmarks, identify 2 possible threatening terrain areas, and then cross the terrain following previously indicated route. Feedback on correct orientation and distance provided after each landmark identification, and information provided about the direction and distance to the next checkpoint.
Participants:	48 university students; 30 males; age range 18 to 44; mean age 24.6 years. Passed test of topographical map knowledge. Relatively VE-naive.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 3.0.
Person-related meas.:	34-item Witmer-Singer ITQ Version 3.0, *VE and computer experience*, *spatial abilities.*
Task-related measures:	Kennedy SSQ, time spent in VE.
Performance measures:	Spatial knowledge acquisition assessed by accuracy in pointing to landmarks from new positions in the terrain, and projective convergence to measure accuracy of cognitive map.

Findings:

(1) Level of equipment and level of detail had no significant relationship with PQ Total or subscales.

(2) Time spent in the VE had a significant positive correlation with PQ Total and Involvement/Control subscale.

(3) ITQ Focus subscale had a significant positive correlation with PQ Total and Involved/Control and Naturalness subscales. ITQ Involvement had a significant negative correlation with PQ Interface Quality.

(4) SSQ Motion Sickness, Disorientation, and Oculomotor subscales had a significant negative correlation with PQ Interface Quality subscale.

(5) Mean number of correct landmark directional identifications, mean number of correct visually available landmark directional identifications, mean correct identifications of individual landmarks, and mean percent of correctly identified visually available individual landmarks had a significant positive correlation with PQ Involvement/Control subscale.

(6) Average projective convergency measures of accuracy and consistency had a significant positive correlation with PQ Interface Quality.

(7) Fidelity and level of abstraction had a significant relationship with landmark identification pointing accuracy, with participants in the Hi-VE condition achieving more accuracy that those in the map condition.

(8) Fidelity had no significant relationship with accuracy and consistency of cognitive maps, but the level of abstraction had a significant effect with improved performance found for the abstract map representation.

(9) Person-related measures (except for ITQ scores) had no significant correlation with spatial knowledge.

(10) Fidelity and type of terrain had a significant relationship with only ITQ Total and Involvement subscale.

(11) SSQ pre-experiment scales had a significant negative correlation with ITQ Focus and Disorientation subscales, and SSQ Oculomotor subscale had a significant positive correlation with ITQ Involvement. SSQ post-experiment scales had no significant correlation with ITQ subscales.

(12) Mean correct identifications of individual landmarks, mean correct directional identifications of visually available landmarks, and mean correct directional identifications of non-visually available landmarks had a significant positive correlation with ITQ Games subscale but had no significant correlation with ITQ Total.

[Singer 1995] Singer, M. J., Ehrlich, J., Cinq-Mars, S., and Papin, J.-P. (December 1995). *Task performance in virtual environments: Stereoscopic versus monoscopic displays and head coupling* (ARI Technical Report 1034). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors:		Stereopsis (present, absent), head tracking (present, absent).
Computing platform:		SGI Reality Engine. Sense8 software.
Visual display:		Flight Helmet HMD with 360 × 240 color pixels/eye, FOV 83°. IPD set for each participant. Participant remained seated.
Tracking:		Polhemus Isotrack for head tracking.
Navigation:		Movement controlled by 6 DOF joystick.
Object manipulation:		Object selection, tracking, manipulation using 6 DOF joystick.
Virtual world:		VEPAB worlds consisting of a series of simple VEs, each focused on one task. No self-representation.
Experimental task:		VEPAB tasks: Doorways—move through 10 rooms with doors at various locations on the opposing walls. Bins—use a 3D crossed-line cursor to select a target ball in one of 9 bins and move it to a bin marked by an "X." Fixed-tracking—place cursor on a stationary 0.7-ft diameter ball-shaped target, where ball appears at locations 5 to 19.5 ft away; target disappears after 20 sec. Moving target—use cursor to track a ball that moves in a straight line with a randomly generated slope, target takes 13 to 19 sec to traverse the room. Distance estimation—identify an object (soldier) starting at 40 ft away and judge its height, then estimate when the object is 30, 20, 10, 5, and 2.5 ft away.
Participants:		48 participants; 36 males; age range 18 to 50; mean age 23.6 years. No prior VE research experience.
Study design:		Between-subjects.
Presence measures:		32-item Witmer-Singer PQ Version 2.0.
Person-related meas.:		29-item Witmer-Singer ITQ, Hidden Figure Test for cognitive style.
Task-related measures:		Kennedy SSQ.
Performance measures:		Doorways—time to cross each room, number of collisions in each room. Bins—time to "grab" ball, total performance time, accuracy. Fixed target—percentage of total time cursor kept on target, time to first intercept. Moving target—percentage of total trial time cursor is kept on target, time to first intercept. Distance estimation—accuracy of distance judgments.
Findings:	(1)	Stereopsis and head tracking had a significant interaction, such that head-tracked participants gave higher PQ Total scores for monoscopic viewing and participants without head tracking gave higher PQ Total scores for stereoscopic viewing. (PQ subscales have differing relationships.)
	(2)	ITQ Total had a significant positive correlation with PQ Total.
	(3)	SSQ Total and subscales had no significant correlation with PQ Total or subscales.
	(4)	Cognitive style had no significant correlation with any of PQ Total and subscales or with ITQ Total and subscales.
	(5)	Performance measures for the tasks had no significant correlation with PQ Total or subscales.
	(6)	*Interaction of stereopsis and head tracking had a significant interaction effect on ITQ Games subscale.*
	(7)	*Pre-test SSQ Oculomotor subscale had a significant positive correlation with ITQ Focus. Post-test SSQ Total and Oculomotor subscale had a significant negative correlation with ITQ Focus.*

[Skalski 2006] Skalski, P., Lange, R., and Tamborini, R. (2006). Mapping the way to fun: The effect of video game interfaces on presence and enjoyment. *Proceedings of the 9th International Workshop on Presence*, Cleveland, USA, August, 63–64.

Factors:		Control device (steering wheel, joystick, keyboard).
Virtual world:		Video game *Need for Speed Underground II*.
Experimental task:		Play video game.
Participants:		48 participants.
Study design:		Between-subjects.
Presence measures:		Spatial presence measure.
Person-related meas.:		*Prior game playing questionnaire*.
Task-related measures:		Perceived interface naturalness measure, enjoyment measure.
Findings:	(1)	Perceived interface naturalness had a significant positive association with spatial presence.
	(2)	Enjoyment had a significant positive association with spatial presence.
	(3)	*Participants using a steering wheel have significantly higher perceived interface naturalness scores.*
	(4)	*Prior game play, prior driving game play, and use of Nintendo Entertainment System also had a significant association with enjoyment.*

[Slater 2004] Slater, M., Pertaub, D.-P., Barker, C., and Clark, D. (2004). *An experimental study on fear of public speaking using a virtual environment.* Paper presented at 3rd International Workshop on Virtual Rehabilitation, Lausanne, Switzerland, September.

Factors:		Anxiety stimulus (empty room, audience).
Computing Platform:		SG Onyx with twin 196-MHz MIPS R10000 processors, InfiniteReality graphics, 192 MB main memory; DIVE software, with Parke and Waters software for generating avatar faces and muscle movement.
Visual display:		Virtual Research VR8 HMD.
Tracking:		Head tracking using Polhemus FASTRAK.
Navigation:		None.
Object manipulation:		None.
Virtual world:		One virtual world was an empty seminar room with table and chairs; the other had the room populated with a neutrally behaving audience of 5 people seated around the table. Behaviors consisted of movement of the upper face to indicate degree of interest, eye contact and direction, and gestures with no intrinsic evaluative content and gestures whose meaning was ambiguous. Avatars' faces and clothing were texture mapped.
Experimental task:		Give a 5-min talk in a seminar room, without notes or other visual aids. (5 min previously given to prepare a talk on a subject of participant's choice.)
Participants:		36 respondents to advertisements; with Personal Report of Confidence as a Public Speaker (PRCS) scores in the bottom third or top third and no evidence of psychotism; 20 confident public speakers, 16 phobic public speakers.
Study design:		Between-subjects.
Presence measures:		Modified post-talk PRCS, self-assessment of somatic response questionnaire, heart-rate.
Person-related meas.:		PRCS questionnaire.
Findings:	(1)	For participants in the phobic group, participants in audience condition gave significantly higher post-talk PRCS scores. Anxiety stimulus had no significant relationship with nonphobic participants. Phobic participants gave significant higher scores than nonphobic participants.
	(2)	For participants in the phobic group, participants in audience condition gave significantly higher self-assessed somatic response scores.

(3) For participants in the phobic group only, anxiety stimulus also had a significant relationship with heart rate trends.

[Slater 2000a] Slater, M., and Steed, A. (2000a). A virtual presence counter. *Presence, 9* (5), 413–434.

Factors:	Movement (reaching out to touch chess piece, mouse click).
Computing platform:	SGI Onyx with twin 196-MHz MIPS R10000 processors, InfiniteReality graphics, and 64 MB main memory. Division dVS and dVise 3.1.2 software.
Visual display:	Stereoscopic Virtual Reality VR4 HMD with 742 × 230 pixels/eye, 170,660 color elements, FOV 67° diagonal with 85% overlap. Frame rate ≥ 20 Hz. Latency ~ 120 ms.
Tracking:	Two Polhemus FASTRAKs for head and mouse tracking.
Navigation:	Moved in direction of gaze at constant velocity by pressing mouse's thumb button.
Object manipulation:	Hand-held 5-button 3 DOF mouse. Interaction with chess piece by either pressing a button on the 3D mouse or reaching out and 'touching' the object.
Virtual world:	Field connected to a virtual anteroom by a door. Field with trees and plants and a 3D chessboard placed on a table positioned 5 m from the door. Self-representation as simple inverse kinematic virtual body, with visible arm and hand. Total polygon count 13,298.
Training:	Provided in a virtual anteroom where participants shown how to move around and how to make a small red cube on a table respond by either touching it or clicking the mouse button.
Experimental task:	Navigate through a door to an outside scene and find 3D chessboard, find and select a specified chess piece, and observe a sequence of moves. Then, press red button and, when sky turns dark, return from field to starting room.
Participants:	20 university students and staff; 18 males.
Study design:	Between-subjects.
Presence measures:	5-item SUS questionnaire, BIPs.
Findings: (1)	For participants in the active groups, movement (taking hand movement into account) had a significant relationship with increased breaks in presence.
(2)	BIPs measure had a significant positive correlation with subjective presence.

[Slater 2000b] Slater, M., Sadagic, A., Usoh, M., and Schroeder, R. (2000b). Small-group behavior in a virtual and real environment: A comparative study. *Presence, 9* (1), 37–51. See also Steed, A., Slater, M., Sadagic, A., Bullock, A., and Tromp, J. (1999). Leadership and collaboration in shared virtual environments. *Proceedings of IEEE Virtual Reality 1999*, Houston, USA, March, 58–63. See also Tromp, J., Bullock, A., Steed, A., and Frécon, E. (1998). Small group behavior experiments in the COVEN project. *IEEE Computer Graphics and Applications, 18* (6), 53–63.

Factors:	Visual display (HMD, desktop).
Computing platform:	SGI Onyx with twin 196-MHz MIPS R10000 processors, InfiniteReality graphics, and 64 MB main memory, running Irix 6.2. SGI High Impact system with 200-MHz R4400 and 64 MB main memory. SGI O2 running at 180 MHz on Irix 6.3 with a MIPS R5000 processor and 32 MB main memory. DIVE 3.2 and RAT v.3.023 system.
Visual display:	Stereoscopic Virtual Reality VR4 HMD with 742 × 230 pixels/eye, 170,660 color elements, FOV 67° diagonal with 85% overlap. Frame rate ≥ 20 Hz. Latency ~ 120 ms. 21-in. monitor, 17-in. monitor.
Audio display:	Earphones.
Tracking:	Two Polhemus FASTRAKs for tracking head and 3D mouse.
Navigation:	Immersive participant moved in direction of gaze at constant velocity by pressing button on 3D mouse. Desktop participants moved using the keyboard arrow keys.
Object manipulation:	None.

Virtual world: Model of actual laboratory where study took place. Includes a virtual room that had sheets of papers displayed around the walls. Each sheet had several words in a column, each word preceded by a number. The words across all sheets with a common number combined to form a saying. Each participant represented by a basic DIVE avatar, differing only in color (Red, Green, Blue) and only visible to immersed (Red) participant. Approximately 3,500 polygons.

Training: Learning to move through the environment.

Experimental task: Group of 3 strangers meets in the VE and locate the room with puzzle. Figures out what puzzle is and then unscrambles as many sayings as possible. One desktop participant (Green) was also tasked to monitor Red as closely as possible, always trying to be in Red's line of vision, moving temporarily when requested by Red. Leaves the VE after about 15 min. Dons jacket the same color as avatar and, after answering a 10-min questionnaire, meets other participants outside the matching real room. Enters real room and continues task for about 15 min.

Participants: 10 groups of 3 participants recruited from a university campus.

Study design: Between-subjects.

Presence measures: 2-item SUS questionnaire, co-presence questionnaire.

Person-related meas.: *Gender*.

Task-related measures: Individual accord questionnaire, including 1 item on enjoyment and an overall rating of accord.

Performance measures: *Number of riddles solved*.

Findings:
(1) Visual display had no significant relationship with presence.
(2) Co-presence had a significant positive correlation with presence.
(3) Individual accord had a significant positive correlation with presence and co-presence and with their combined scores.
(4) Number of riddles solved had a significant positive association with individual accord.
(5) Gender had a significant association with individual accord. Females reported increased accord.

[Slater 1999] Slater, M., Pertaub, D.-P., and Steed, A. (1999). Public speaking in virtual reality. *IEEE Computer Graphics and Applications, 19* (2), 6–9.

Factors: Visual display (HMD, monitor), audience response type (positive, negative).

Computing platform: SGI Onyx with twin 196-MHz MIPS R10000 processors, InfiniteReality graphics, and 192 MB main memory. DIVE V3.3 software.

Visual display: Stereoscopic VR4 HMD with 742 × 230 pixel resolution/eye, FOV 67° at 85% overlap, 170,660 color elements. Frame rate ≥ 10 Hz in stereo. Display lag ~ 100 ms.

Tracking: 2 Polhemus FASTRAKs for HMD and mouse.

Navigation: Move in gaze direction at constant velocity when thumb pressed a button on hand-held 5-button 3 DOF mouse.

Object manipulation: None.

Virtual world: Virtual seminar room populated with audience of 8 avatars seated in semicircle. Avatars continuously displayed scripted behaviors (with human-operator-directed timing), such as paying attention, clapping, talking to other audience members, head and body movements, and random behaviors (e.g., twitching and blinking).

Experimental task: Practice a 5-min talk with a positive audience and a negative audience. Then, give talk to an audience that begins as hostile and ends up positive.

Participants: 10 students and faculty members; 9 males; age range 20 to 40.

Presence measures: 4-item co-presence questionnaire.

Task-related measures: Perceived audience interest rating, self-rating of performance.

Findings:
(1) Visual display had no significant relationship with co-presence.

	(2)	For monitor participants, self-rating of performance had a negative correlation with co-presence. For HMD participants, rating had a negative correlation for the negative audience and positive correlation for the positive audience.
	(3)	*Perceived audience interest had a positive correlation with self-rating of performance for a negative audience only.*

[Slater 1998] Slater, M., Steed, A., McCarthy, J., and Maringelli, F. (1998). The influence of body movement on subjective presence in virtual environments. *Human Factors, 40* (3), 469–477.

Factors:		Movement (trees with large variation in height, low variation in height), task complexity (count number diseased plants, count and remember location of diseased plants).
Computing platform:		SGI Onyx with twin 196-MHz MIPS R10000 processors, InfiniteReality graphics, and 64 MB main memory. Division dVS and dVise 3.1.2 software.
Visual display:		Stereoscopic VR4 HMD with 742 × 230 pixel resolution/eye, FOV 67° at 85% overlap, 170,660 color elements. Frame rate ≥ 10 Hz in stereo. Display lag ~ 100 ms.
Tracking:		Polhemus FASTRAK for HMD and mouse.
Navigation:		Move in gaze direction at constant velocity when thumb pressed a button on hand-held 5-button 3 DOF mouse.
Object manipulation:		None.
Virtual world:		Training lab connected by a door to a 90 × 75 m field containing 150 plants or trees with large leaves, distributed randomly through the field. Each tree was 2.4 m across and had 16 leaves. Healthy trees had green leaves, and diseased trees had leaves (1 or 4) with brown underside. Trees were classified as follows in equal proportion: healthy trees, trees with 1 bad leaf, or trees with 4 bad leaves. Distribution of heights 1.7 ± 0.1 m for low-variation field and 2.35 ± 1.9 m for high-variation field. Self-representation as simple inverse kinematic virtual body. Total scene 32,576 triangles.
Training:		Training tasks in a virtual lab matching real lab where experiment performed.
Experimental task:		Simple task: move through the field to count the number of diseased plants. Complex task: count the number of diseased plants and remember where they were to later draw on a map. After about 3 min, sky brightened as a signal to start moving back to training lab.
Participants:		20 university students and staff, and journalists; 13 males.
Study design:		Between-subjects.
Presence measures:		6-item SUS questionnaire.
Person-related meas.:		Gender.
Task characteristics:		Task complexity.
Findings:	(1)	Movement had a significant association with reported presence: positive for head yaw, negative for extent of bending.
	(2)	Task complexity and gender had a significant interaction, such that females in the more complex task reported significantly lower presence than those in the simpler task.

[Slater 1996] Slater, M., Usoh, M., Linakis, V., and Kooper, R. (1996). Immersion, presence and performance in virtual environments: An experiment with tri-dimensional chess. *Proceedings of Virtual Reality Software and Technology (VRST '96)*, Hong Kong, July, 163–172.

Factors:	Visual display (HMD, desktop), scene realism (realistic setting with chess board in a garden setting, plain setting with chessboard suspended in void).
Computing platform:	Division ProVision 100 system. Board and chess pieces modeled in AutoCAD.
Visual display:	Stereoscopic, color Virtual Reality VR4 HMD with 360 × 240 pixels per eye (overall 704 × 480), FOV ~ 75° H × 40° V. Frame rate 15–20 Hz.

Tracking: Polhemus FASTRAK for tracking hand and mouse.
Navigation: Division 3D mouse. Forward movement accomplished by pressing a left thumb button, backward movement accomplished by pressing a right thumb button.
Object manipulation: Objects can be touched by virtual hand and grabbed using trigger button on mouse.
Virtual world: 3D chessboard placed on a table in a realistic garden setting (an open field that also contained a chair, a tree, and small plant) with a sky dome, or suspended in a void. Self-representation as virtual hand. Garden texture mapped. Total garden scene of 7,732 triangles, 6,276 in plain environment.
Training: Introduction to 3D chess given in real world. Training in moving and selecting objects conducted in a VE similar to that used in the study.
Experimental task: Initiate game by pressing red button near chessboard. When a chess piece changes color, touch this piece and watch its movement. Press red button again to repeat moves until participant is confident that he/she can remember which pieces move and to where they move and can later reproduce final state of the board on a real 3D chessboard.
Participants: 24 participants; 16 males. Some had prior VE experience.
Study design: Between-subjects.
Presence measures: Multi-item questionnaire including 3 items related to presence.
Person-related meas.: Spatial Awareness Test, *gender*, *chess experience*.
Task-related measures: Practice, viewing time, level of nausea, confidence (that moves were remembered, correctly reproduced).
Performance measures: Number of correct moves.
Findings:
(1) HMD participants reported significantly more presence.
(2) Scene realism had no significant relationship with presence.
(3) For immersed participants, the Spatial Awareness Test scores had a significant negative relationship with presence.
(4) Presence had no significant relationship with task performance.
(5) HMD participants made significantly more correct moves.
(6) Participants with the scenic virtual world made significantly more correct moves.
(7) Chess experience and amount of virtual practice had significant positive association with performance.
(8) Males made significantly more correct moves. For females, Spatial Awareness Test scores had a significant positive correlation with performance.

[Slater 1995a] Slater, M., Usoh, M., and Steed, A. (1995a). Taking steps: The influence of a walking technique on presence in virtual reality. *ACM Transactions on Computer-Human Interaction, 2* (3), 201–219. See also Slater, M., M., Usoh, M., and Steed, A. (1994). Steps and ladders in virtual reality. *Proceedings of Virtual Reality Software and Technology: VRST '94,* Singapore, August, 45–54.

Factors: Navigation (walking-in-place, 3D mouse).
Computing platform: Division ProVision 200 system.
Visual display: Stereoscopic, color Virtual Reality Flight Helmet with 360 × 240 pixels per eye, FOV 75° H. Frame rate ~ 15 fps.
Tracking: Polhemus sensors for tracking head and mouse.
Navigation: Movement by pressing a button on a Division 3D mouse, with direction controlled by pointing or walking-in-place technique.
Object manipulation: Division 3D mouse used for grasping objects by intersecting the virtual hand with an object and pulling the trigger button.
Virtual world: A corridor with a door leading to a room containing a chasm over another room 20 ft below, with a wide ledge around the room. Self-representation as virtual body.
Experimental task: Pick up an object, take it into a room, and place it on a chair placed on the far side of a chasm.
Participants: 16 participants from university campus. No prior VE experience.
Study design: Between-subjects.

Presence measures:	Multi-item questionnaire including 3 items related to presence. Observation of whether participants moved around the ledge or across chasm.
Task-related measures:	Rating of degree of nausea, extent of association with virtual body.
Findings: (1)	For participants in walking-in-place condition, association with virtual body had a significant positive correlation with presence.
(2)	Path taken over chasm had a significant association with lower presence.
(3)	Reported nausea had a significant positive association with presence.

[Slater 1995b] Slater, M., Usoh, M., and Chrysanthou, Y. (1995b). The influence of dynamic shadows on presence in immersive virtual environments. *Proceedings of the 2nd Eurographics Workshop on Virtual Reality,* Monte Carlo, January–February, 8–21.

Factors:	Dynamic shadows (shadows for red spears, no shadows).
Computing platform:	Division ProVision system with dVS Version 0.3, Gouraud shading.
Visual display:	Flight Helmet HMD with 360 ×x 240 pixels per eye, FOV 75° H. Frame rate without shadows 9 Hz; frame rate with shadows 6–8 Hz.
Audio display:	Real radio.
Tracking:	Head tracking.
Navigation:	Pressing center thumb button on a Division 3D mouse for forward movement in direction of gaze.
Object manipulation:	Press left button on a Division 3D mouse to fire a spear; spear moves in direction determined by hand orientation until button released (then spear cannot be reactivated). Press right button to act as “infrared” radio switch. Additional button used to select objects.
Virtual world:	Virtual room 10 × 6 m. Five red spears near one wall, positioned with 10-cm variation behind a screen. Virtual radio positioned immediately in front of screen. Red square on floor positioned 3 m in front of screen. Four point light sources on wall facing red spears (used for dynamic shadows condition). Fixed target on wall at 90° to wall, with red spears. Green spear that moves at mean velocity of 92 cm/sec (without shadows) and at 47 cm/sec (with shadows). Spears cast shadows that reflect their movement. Self-representation as virtual body. Total scene 413 triangles.
Training:	Practice run in VE with experimenter talking participant through experimental task.
Experimental task:	Move to red square, face red spears, and select spear nearest to wall. Move to selected spear, pick it up, return to red square, and turn to face target on far wall. Orient spear on target and launch spear, guiding it with hand movements. Stop spear the instant it reaches the target. Then take green spear to red square. Meanwhile, when radio starts, point to it and use “infrared” switch to turn it off.
Participants:	8 participants from a university campus.
Study design:	Within-subjects.
Presence measures:	6-item SUS questionnaire. Pointing to the position of a radio (switching on/off) when position of radio in the real world differed from that in the virtual world.
Person-related meas.:	Personal representation system (visual, auditory, kinesthetic) and perceptual position (exocentric, egocentric) Neurolinguistic Programming (NLP) assessment.
Performance measures:	*Selection of correct spear, accuracy in estimating distance from target center and distance from wall*.
Findings: (1)	Use of dynamic shadows was associated with significantly higher reported and objective behavioral measures for participants dominant in the visual sense.
(2)	Reported presence had a significant positive association with objective behavioral measure of presence.
(3)	*Use of dynamic shadows had an association with significantly increased accuracy in distance to wall performance estimates.*

[Slater 1995c] Slater, M., Alberto, C., and Usoh, M. (1995c). In the building or through the window? An experimental comparison of immersive and non-immersive walkthroughs. Paper presented at VII Encontro Portugues de Computacao Grafica, Eurographics, Monte de Caparica, Portugal, February. See also Usoh, M., Alberto, C., and Slater, M. (1996). *Presence: Experiments in the psychology of virtual environments*. University College London, UK, Department of Computer Science. Available:
http://www.cs.umu.se/kurser/TDBD12/VT07/articles/precense-paper-teap_full96.pdf

Factors:		Visual display (HMD, desktop), color (VE matched to real location, matched to incorrect real location), elapsed time (same day visit to test building, 24 hrs later).
Computing platform:		Division ProVision 100 system. VE modeled using AutoCAD.
Visual display:		Flight Helmet HMD with 360 × 240 pixels per eye, FOV 75° H. TV screen used for nonimmersive condition (HMD placed on swivel chair in front of participant to use same method of setting viewpoint).
Tracking:		Polhemus FASTRAKs for tracking head and mouse.
Navigation:		Forward movement by pressing left thumb button on a Division 3D mouse; backward movement by pressing right thumb button.
Object manipulation:		None.
Virtual world:		Representation of Computer Science Department in a building. Self-representation as 3D arrow cursor.
Training:		Participants were shown how to navigate through the virtual building.
Experimental task:		Search for a plant but only go through open doors. Then in a real building, visit two locations and select the one that matches the one in the VE. Then, in matching location, find the plant (in same location as in VE). Participants stayed in each type of environment for about 15 min.
Participants:		24 participants recruited from a university campus; 12 males. Two had prior VE experience.
Study design:		Between-subjects.
Presence measures:		6-item SUS questionnaire. Additional question relating to “sense of having been there before.”
Person-related meas.:		10-item NLP questionnaire.
Performance measures:		Time to find plant in VE and real building, accuracy of selection in matching VE and real-world locations.
Findings:	(1)	Visual display, color, and elapsed time had no significant association with presence.
	(2)	Ratio of time to find plant in real world to time to find plant in virtual world had a negative correlation with presence for a participant dominant in the auditory sense.
	(3)	*Visual display, color, and elapsed time had no significant association with either performance measure.*

[Slater 1994] Slater, M., Usoh, M., and Steed, A. (1994). Depth of presence in virtual environments. *Presence, 3* (2), 130–144.

Factors:	Stacking type (transported between environments by donning virtual HMD, going through doors) and stacking depth (2, 4, 6), gravity (present, absent), virtual actor (following subject, staying in one position), visual cliff (present, absent).
Computing platform:	Division ProVision 200 system.
Visual display:	Virtual Reality Flight Helmet with resolution of 360 × 240 pixels, FOV 75° H. Frame rate 7–16 Hz. Subject standing, able to walk within range determined by trackers.
Tracking:	Polhemus sensors for head tracking and 3D mouse (sampling rate 30 Hz).
Navigation:	Navigation by pressing middle button on a Division 3D mouse, with direction determined by the direction in which the hand is pointed. Movement with constant velocity or a single small step can be made by a single button click.

Object manipulation: Object selection using Division's 3D mouse trigger.
Virtual world: Initial scene consisting of empty room with cupboard and 12-in. cube. Subsequent scenes: (1) typical living room with sofas, table, TV; (2) abstract scene with randomly scattered cubes of different sizes/colors; (3) typical office setting with desks, swivel chairs, computer, and filing cabinet; (4) kitchen with cupboards and cooker; (5) bar and bar furniture; and (6) cliff with plank across a lower-level room with sofa, table, and chair. Self-representation as virtual body. Sound to mark transition between levels when using virtual HMD; also light touch on participant's back.
Training task: In initial scene, practice how to move, pick up objects, and open cupboard doors for up to 5 min.
Experimental task: Scenario based on a mixture of *Excalibur* and *Beauty and the Beast*. Task to find a set of swords, embedded in stone, hidden in the environment, and pull out the 1 sword that could be moved. Find a nearby well and drop the sword down the well. The Beast was awakened when the correct sword was found.
Participants: 23 participants from a university campus.
Study design: Between-subjects.
Presence measures: Multi-item questionnaire with 3 items relating to presence. Observation of whether participant moved real body to match virtual body.
Person-related meas.: 11-item NLP questionnaire.
Findings:
(1) Stacking depth had a significant relationship with presence—a positive relationship when using a HMD and negative relationship when transported via doors.
(2) Focus on visual or kinesthetic representation systems had a significant positive association with presence. Focus on auditory representation system had a significant negative association with presence.
(3) Gravity, virtual actor, and visual cliff were not associated with any significant differences in presence scores.
(4) Aligning real and virtual bodies had no significant correlation with subjective presence.

[Slater 1993a] Slater, M., and Usoh, M. (1993a). The influence of a virtual body on presence in immersive virtual environments. *Proceedings of the 3rd Annual Conference on Virtual Reality*, London, UK, April, 34–42. See also Slater, M., and Usoh, M. (1993b). Presence in immersive virtual environments. *Proceedings of the IEEE Virtual Reality Annual International Symposium (VRAIS '93)*, Seattle, USA, September, 90–96. See also Slater, M., and Usoh, M. (1993c). Representations systems, perceptual position, and presence in immersive virtual environments. *Presence, 2* (3), 221–233. See also and Slater, M., and Usoh, M. (1992). *An Experimental Evaluation of Presence in Virtual Environments* (Report QMW-DCS01993-689). London, UK: Queen Mary and Westfield College, University of London, Department of Computer Science.

Factors: Self-representation (virtual body, arrow cursor).
Computing platform: Division ProVision 200 system.
Visual display: Flight Helmet HMD with 360 × 240 pixels per eye, FOV 100° H x 60° V. Frame rate 8–16 fps.
Audio display: HMD headphones.
Tracking: Two Ascension Technology's Flock of Birds used for tracking of head and mouse.
Navigation: Forward movement accomplished by pressing left thumb button on a Division 3D mouse; backward movement by pressing right thumb button. Move in direction of pointing.
Object manipulation: Selection of objects using mouse trigger.
Virtual world: Corridor showing 6 doors on the left-hand side. A cube was positioned in the middle of the corridor. Room 1 contained everyday objects that might be found in an office. Room 2 contained various objects that would fly toward the subject at body level. Room 3 held a set of different colored blocks. Room 4 contained objects that would fly toward the subject's face. In Room 5, standard floor and

	ceiling patterns (and the virtual body when present) were reversed. Room 6 consisted of a chessboard with 2 pieces and a plank over a chasm that contained another chess board about 18 ft below. Sound cues when an object is grabbed or a door opens.
Training:	Once in VE, told how to operate navigation controls. Then instructed to walk to far end of corridor and then back to cube. Instructed how to pick it up. Move cube around and drop it.
Experimental task:	Visit each room. In Room 1, navigate to the other side of the room, stop, and then return back to corridor. In Room 3, build a pile using all the blocks. In Room 6, pick up a chess piece and drop it over the edge of the plank onto the lower chessboard. Total time ranged from 13 to 27 min.
Participants:	17 graduate students studying human computer interaction.
Study design:	Between-subjects.
Presence measures:	6-item SUS questionnaire. Observation of reaction to situations of relative danger.
Person-related meas.:	NLP assessment. Self-rating of adaptation to new environments.
Task-related measures:	Loss of realism as indicated in responses to open-ended questions.
Findings: (1)	Participants with a virtual body gave significantly higher SUS scores.
(2)	Focus on visual senses was associated with significantly increased presence; focus on auditory senses was associated with lower presence.
(3)	For participants with a virtual body, focus on kinesthetic senses was associated with significantly increased presence. For those without a body, focus on kinesthetic senses was associated with significantly decreased presence.
(4)	Participants who mentioned problems with a loss of realism (things do not behave realistically) gave significantly lower presence scores.
(5)	Considered separately, reaction to height and reaction to flying objects had no relationship with subjective presence, but a reaction to either was more likely to occur for a lower sense of presence.
(6)	Participants self-rated as fast adapters to new environments reported a lower sense of presence.

[Snow 1996 (1)] Snow, M. P. (December 1996). *Charting presence in virtual environments and its effects on performance*. Doctoral dissertation, Virginia Polytechnic and State University. Blacksburg, VA. See also Snow, M. P., and Williges, R. C. (September 1998). Empirical models based on free-modulus magnitude estimation of perceived presence in virtual environments. *Human Factors, 40* (3), 386–402.

Factors:	Update rate (8, 12, and 16 Hz), display resolution (320×200 and 640×480), FOV ($48° H \times 36° V$, $36° H \times 27° V$, and $24° H \times 18° V$).
Computing platform:	2 Pentium PCs, Superscape VRT software with collision modeling.
Visual display:	Monoscopic VR4 HMD with FOV and resolution varying across experimental conditions. Viewpoint and eye level set at participant's standing eye level. Viewpoint attached to invisible body that measured 16.5 in. front-to-back and side-to-side. Participants standing at a swiveling platform.
Audio display:	HMD headphones.
Tracking:	Ascension Technology's Flock of Birds for head tracking.
Navigation:	Logitech Magellan 6 DOF control device (3 DOFs disabled) resting on platform.
Object manipulation:	Standard mouse on platform; left-click to interact with objects beneath the cursor.
Virtual world:	Rooms connected by corridors with left and right turns and an elevator. Floors have checkerboard pattern; walls 8 ft high with narrow vertical stripes every 5 ft; ceilings with horizontal light panels every 10 ft; corridors 3 ft wide. One room has desk, chair, filing cabinets, wall-mounted vertical rack of open bins, clock on wall; 2 other rooms with fewer objects. Self-representation as arrow cursor. No texture mapping.
Training:	Pen-and-paper practice in magnitude estimation. Guided walk-through and demonstration of each task. One practice trial for each task.

Experimental task: 5 tasks: distance estimation of moving target (40 ft and less), bins task, moving through corridors, detect moving target, choose static target. Average total time 2.5 hrs.

Participants: 12 participants; age range 16 to 42; mean age 22 years.

Study design: Within-subjects.

Presence measures: Magnitude estimation as ratio-scale measure of presence.

Task-related measures: Time spent in VE.

Performance measures: Locomotion time to complete and number of errors, distance estimation accuracy, bins task response time, moving target response time, choice response time.

Findings:

(1) Faster update rates (16, 12, 6 Hz), increased resolution, and larger FOV were associated with significantly higher presence ratings.

(2) Time spent in VE had a significant positive relationship with presence.

(3) Time to complete and errors made in turns task, and time to complete search task had a significant negative correlation with presence. Time to complete bins task and time to complete choice task had no significant correlation.

(4) Update rate had a significant relationship with time to complete turns task and choice performance, with less time taken for faster update rates. Update rate had no significant relationship with distance estimation accuracy, time to complete bins task, errors made during turns task, and search performance.

(5) Display resolution had a significant relationship with distance estimation accuracy and search performance, with improved performance for increased resolution. Display resolution had no significant relationship with time to complete bins task, errors made during turns task, time to complete turns task, and choice performance. The interaction between display resolution and FOV had a significant relationship with search performance.

(6) FOV had a significant relationship with distance estimation accuracy and search performance, with improved performed for larger FOVs, FOV had no significant relationship with time to complete bins task, errors made during turns task, time to complete turns task, and choice performance.

[Snow 1996 (2)] Snow, M. P. (December 1996). *Charting presence in virtual environments and its effects on performance*. Doctoral dissertation, Virginia Polytechnic and State University. Blacksburg, VA. See also Snow, M. P., and Williges, R. C. (September 1998). Empirical models based on free-modulus magnitude estimation of perceived presence in virtual environments. *Human Factors, 40* (3), 386–402.

Factors: Audio cues (auditory feedback when subject bumped into objects and clicked on interacting objects; context-appropriate sounds; none), texture mapping (textures applied to doors, walls, bins, and other objects; none), head tracking (present, absent), stereopsis (present, absent), virtual personal risk (rear elevator doors missing, doors present).

Computing platform…

Performance measures: As in [Snow 1996 (1)], except Visual Display employed FOV 48° H × 36° V, resolution 640 × 480 and update rate fixed at 8 Hz.

Findings:

(1) Sound, texture mapping, head tracking, and stereopsis had a significant positive relationship with presence.

(2) Virtual personal risk and time spent in VE had no significant relationship with presence.

(3) Errors made in locomotion task had a significant negative correlation with presence, but time to complete the bins, turns, search, and choice tasks had no significant correlation.

(4) Audio cues had no significant relationship with distance estimation, time to complete bins task, time to complete turns task, time to complete search task, and choice performance.

	(5)	*Texture mapping had a significant relationship with distance estimation. An interaction between audio cues and texture mapping also had a significant relationship with errors in turns task.*
	(6)	*Use of head tracking was associated with reduced errors in turns task, time to complete turns task, and time to complete search task. There was a significant interaction with texture mapping for time to complete bins task.*
	(7)	*Use of stereo vision was associated with significantly more accurate distance estimation. There was a significant interaction with audio cues for relationship with distance estimation and time to complete bins task.*
	(8)	*Virtual personal risk had a significant relationship with errors in turns task and time to complete search task.*

[Snow 1996 (3)] Snow, M. P. (December 1996). *Charting presence in virtual environments and its effects on performance*. Doctoral dissertation, Virginia Polytechnic and State University. Blacksburg, VA.

Factors:		Level of interaction (6, 12, 18 interactions possible), second user (present, absent), detail (low, medium, high).
Computing platform…		
Performance measures:		As in [Snow 1996 (2)].
Findings:	(1)	Level of interactions possible and level of detail had no main effect but had a significant interaction effect on presence, such that higher levels of presence.
	(2)	Inclusion of a second user was associated with significantly more presence. There was a significant interaction with environmental detail and number of interactions.
	(3)	Time in VE had a significant positive relationship with presence.
	(4)	Time to complete bins, turns, and search tasks and errors made in turns task had a significant negative correlation with presence. Time to complete the choice task had no significant correlation.
	(5)	*Level of interaction, second user, and level of detail had no relationship with any performance measure.*

[Steed 1999] Steed, A., Slater, M., Sadagic, A., Bullock, A., and Tromp, J. (1999). Leadership and collaboration in shared virtual environments. *Proceedings of IEEE Virtual Reality 1999,* Houston, USA, March, 58–63.

Factors:	Visual display (HMD, desktop).
Computing platform:	SGI Onyx with twin 196-MHz MIPS R10000 processors, InfiniteReality graphics, and 192 MB main memory. SGI Indigo with a 200-MHz R4400 MIPS processor, High Impact graphics, 192 MB main memory. SGI Octane with a 195-MHz MIPS R10000 processor, 128 MB main memory. dVS and audio server. Integrated Services Digital Network (ISDN) connection. DIVE 3.2 software.
Visual display:	Virtual Research VR4. Two desktop monitors.
Tracking:	Two Polhemus FASTRAKs for tracking HMD and 3D mouse.
Navigation:	Immersive participant moved in direction of gaze at constant velocity by pressing button on 3D mouse with 5 buttons. Desktop participants moved using a standard mouse with 3 buttons.
Virtual world:	Model of actual laboratory where study took place. Includes a virtual room that had sheets of papers displayed around the walls. Each sheet had several words in a column, each word preceded by a number. The words across all sheets with a common number combined to form a saying. Each participant represented by a basic DIVE avatar, differing only in color (Red, Green, Blue), only visible to immersed (Red) participant.
Training:	Learning to move through the environment. 4–5 min.
Experimental task:	Group of 3 strangers meets in the VE and locates the room with puzzle. Figures out what puzzle is and then unscrambles as many sayings as possible. 15-min time

		limit. Dons jacket the same color as avatar and, after answering a 10-min questionnaire, meets other participants outside the matching real room. Enters real room and continues task for about 15 min.
Participants:		20 groups of 3 participants (data unavailable for 8 of these participants).
Study design:		Between-subjects.
Presence measures:		6-item SUS questionnaire, 8-item co-presence questionnaire.
Task-related measures:		7-item accord questionnaire.
Findings:	(1)	Visual display had no significant relationship with presence and co-presence.
	(2)	Presence had a significant positive correlation with co-presence.
	(3)	Accord had a significant positive correlation with co-presence.

[Stevens 2002] Stevens, B., Jerrams-Smith, J., Heathcote, D., and Callear, D. (2002). Putting the virtual into reality: Assessing object-presence with projection-augmented models. *Presence, 11* (1), 79–92.

Computing platform:		PC with 166-MHz Pentium processor, 40 MB RAM.
Visual display:		3M MP8725 LCD projector, 800 × 600 resolution, 52 × 38 cm total image array projected on an A1 sheet of white paper. Participants seated in darkened room.
Audio display:		None.
Navigation:		Standard mouse.
Object manipulation:		Standard mouse.
Projected model:		Microsoft Paint. Physical model consisted of a white, plaster-covered polystyrene representation of a mobile telephone approximately 4× size of conventional mobile phone.
Training:		3-min practice task using the drawing package projected onto a flat white surface.
Experimental task:		Design a color scheme for a mobile telephone case, directly on the model's surface. 15-min time limit.
Participants:		16 participants; 8 males; age range 22 to 39; mean age 29 years. Computer literate but without experience in drawing packages.
Presence measures:		Object Presence Questionnaire (OPQ).
Person-related meas.:		Witmer-Singer ITQ, age, gender, drawing application competency, design type.
Task-related measures:		*Task completion time*.
Findings:	(1)	Task completion time had no significant correlation with OPQ Total or any OPQ subscales.
	(2)	Total ITQ scores had no significant correlation with OPQ scores. For males, ITQ Focus subscale had a significant positive correlation with OPQ Total and Involvement/Control and Natural subscales, and ITQ Involvement subscale had a significant positive correlation with OPQ Involvement/Control subscale. For females, ITQ Total and Games subscale had a significant negative correlation with OPQ Natural subscale, and ITQ Involvement subscale had a significant negative correlation with OPQ Involvement/Control.
	(3)	Age, gender, drawing application competency, and design type had no significant correlation with OPQ Total or any OPQ subscales.
	(4)	*Age and gender had a significant correlation with ITQ Games subscale only. Drawing application competence and design type had no significant correlation with ITQ Total or any ITQ subscales.*
	(5)	*Task completion time had no significant correlation with ITQ Total or any ITQ subscales*.

[Takatalo 2004] Takatalo, J., Häkkinen, J., Komulainen, J., Särkelä, H., and Nyman, G. (2004). The experiential dimensions of two different digital games. *Proceedings of the 7th Annual International Workshop on Presence,* Valencia, Spain, October, 274–278.

Factors:		Visual display (Eye-Trek, monitor), game content (Need for Speed Underground (NFS UG), Slicks n' Slide)).

Computing platform:		Pentium IV with Sapphire ATI Technologies, Inc. Radeon 9600 256-MB display adapter, Realtek AC97 sound card.
Visual display:		Olympus Eye-Trek FMD-700 near-eye display, 21-in. monitor.
Navigation:		Microsoft sidewinder Gamepad for NFS UG; keyboard for Slicks n' Slide.
Virtual world:		NFS UG is a 1st person 3D driving game with camera movement. Slicks n' Slide 1.30d is a 3rd person 2D driving game with no camera movement and static environment.
Experimental task:		Play game for 40 min.
Participants:		80 participants, mainly behavioral sciences and computer science students; 40 males; mean age 24.7 years. Excluded people who did not like driving games, had no computer game playing experience, or played computer games at least or more than 6 hrs/day.
Study design:		Between-subjects.
Presence measures:		146-item Experimental Virtual Environment-Experience Questionnaire (EVEQ) with Physical presence, Emotional involvement, Situation involvement, and Performance competence subscales.
Findings:	(1)	Participants who played NFS UG gave significantly higher Physical presence, Emotional involvement, and Situation involvement scores. Game content had no significant relationship with Performance competence scores.
	(2)	For monitor participants, those who played NFS UG gave significantly higher Physical presence and Emotional involvement scores.
	(3)	For Eye-Trek participants, those who played NFS UG gave significantly higher Physical presence, Emotional involvement, and Situational involvement scores.
	(4)	Within Situational involvement, participants who played NFS UG with the Eye-Trek reported significantly higher scores for arousal, interaction, involving test situation, and less boring game. With the monitor, NFS UG was significantly more amusing.

[Tang 2004] Tang, A., Biocca, F., and Lim, L. (2004). Comparing differences in presence during social interaction in augmented reality versus virtual reality environments: An exploratory study. *Proceedings of the 7th Annual International Workshop on Presence,* Valencia, Spain, October, 203–207.

Factors:		Environment type (augmented reality, virtual reality).
Computing platform:		Software developed using ImageTclAR.
Visual display:		Stereoscopic Sony Glasstron LDI-100B HMD.
Tracking:		Head tracking using InterSense IS-900 tracker.
Augmented environ.:		Black room where a set of virtual cell phones are presented on a physical table, with a partner across the table (played by an experimenter).
Virtual world:		Representation of augmented environment, with avatar representing partner.
Experimental task:		Carry out social discussion with partner about personal preferences about 2 cell phone models.
Participants:		16 undergraduates; 11 males. No prior experience with Virtual Reality/Augmented Reality (VR/AR).
Study design:		Within-subjects.
Presence measures:		ITC-SOPI.
Findings:	(1)	Participants in the AR condition gave significantly higher scores for the Spatial Presence subscale.

[Thie 1998] Thie, S., and van Wijk, J. (1998). A general theory on presence. *Proceedings of the 1st International Workshop on Presence*, Ipswich, UK, June. Available:
http://www.cs.ucl.ac.uk/staff/m.slater/BTWorkshop/KPN/

Factors:		Social presence manipulation (choose avatar, choose nickname, personal information provided, trace other participants, gestures, moderator, know who said/did what, 3-person audio connection; none).
Computing platform:		4 multimedia PCs running NT and Win '95. Software included Netscape Navigator 3.01, Blaxxun Cyberhub, and Passport multiuser clients/servers.
Visual display:		Desktop monitors.
Object manipulation:		None.
Virtual world:		Shared Virtual Environment (SVE).
Training:		Practice with the SVE.
Experimental task:		Decision-making tasks.
Participants:		48 participants; 24 males. Experienced in Internet browsing; no prior experience with similar experiment.
Study design:		Between-subjects.
Presence measures:		Psotka's 21-item virtual presence and Thie's social presence questionnaires, extremity of decision made, come-back rate.
Person-related meas.:		Psotka's 15-item Susceptibility for Presence Questionnaire.
Findings:	(1)	Social presence manipulation had no relationship with social and virtual presence scores or extremity of decision making. Increased social presence was associated with a significantly increased come-back rate.
	(2)	Social virtual presence had a significant positive correlation with virtual presence.
	(3)	Come-back rate had a significant positive correlation with virtual presence but had no significant relationship with social virtual presence.
	(4)	Susceptibility for presence had no significant correlation with virtual presence.

[Tromp 1998 (2)] Tromp, J., Bullock, A., Steed, A., and Frécon, E. (1998). Small group behavior experiments in the COVEN project. *IEEE Computer Graphics and Applications, 18* (6), 53–63. See also Steed, A., Slater, M., Sadagic, A., Bullock, A., and Tromp, J. (1999). Leadership and collaboration in shared virtual environments. *Proceedings of IEEE Virtual Reality 1999,* Houston, USA, March, 58–63.

Factors:	Avatar realism (realistic, basic), visual display (HMD, monitor).
Computing platform:	UCL machines SGI Onyx with twin 196-MHz MIPS R10000 processors, InfiniteReality graphics, 192 MB main memory; SGI Indigo with a 200-MHz R4400 processor and 64 MB main memory; audio server. Nottingham machine SGI Indigo with a 200-MHz R4400 processor, High Impact graphics, 192 MB main memory. Fraunhofer Institut fur Integrierte Schaltungen (IIS)[3] machine SGI Octane with a 195-MHz MIPS R10000 processor and 128 MB main memory. dVS/dVise 5.0 and RAT software. ISDN connections with mean round trip times overall all trials being 100 ms between Nottingham and UCL, 450 ms between Nottingham and IIS, and 300 ms between UCL and IIS.
Visual display:	Virtual Research VR4, resolution 742 × 230 pixels/eye, FOV 67° diagonal, with 85% overlap, 170,660 color elements. 2 desktop monitors with 21-in. screen. Frame rate 20–30 Hz on all machines. Latency ~ 120 ms.
Tracking:	Polhemus FASTRAKs for head and mouse tracking.
Navigation:	5-button mouse or keyboard arrow keys.
Object manipulation:	None.
Virtual world…	

[3] Fraunhofer Institut fur Integrierte Schaltungen = Fraunhofer Institute for Integrated Circuits.

Experimental task:		As in [Slater 2000b].
Participants:		4 groups of 3 participants from a university campus.
Study design:		Between-subjects.
Presence measures:		Presence questionnaire, co-presence questionnaire.
Task-related measures:		7-item group accord questionnaire.
Findings:	(1)	Avatar realism had no significant relationship with presence.
	(2)	Visual display had no significant relationship with presence or co-presence.
	(3)	Co-presence had no significant correlation with presence.
	(4)	Group accord had a significant positive correlation with co-presence but had no significant correlation with presence.

[Uno 1997] Uno, S., and Slater, M. (1997). The sensitivity of presence to collision response. *Proceedings of the 1997 Virtual Reality Annual International Symposium (VRAIS '97),* Albuquerque, USA, March, 95–103.

Factors:		Collision response where realism of collisions manipulated using elasticity (1.0, 0.7), friction (0.7, 0.0), shape (ellipsoid, true shape).
Computing platform:		Division ProVision100.
Visual display:		Virtual Research Flight Helmet HMD, with 360 × 240 pixel resolution/eye, FOV 75° H × 40° V.
Tracking:		Polhemus FASTRAK for head and mouse tracking.
Navigation:		Move by pressing button on a Division 3D mouse.
Object manipulation:		Objects grabbed using trigger button on a 3D mouse.
Virtual world:		Self-representation as virtual hand.
Experimental task:		Two games of pin bowling, with one collision parameter changed between games.
Participants:		18 students and other college staff; 12 males.
Presence measures:		6-item SUS questionnaire.
Task-related measures:		1 question on experience of dizziness, sickness, or nausea.
Findings:	(1)	Elasticity and shape had no significant relationship with presence. For friction, the relationship was positive with correct shape and negative with elasticity.
	(2)	Prior VR experience had a significant negative relationship with presence.
	(3)	Simulator sickness had a significant negative association with presence.

[Usoh 2000] Usoh, M., Catena, E., Arman, S., and Slater, M. (2000). Using presence questionnaires in reality. *Presence, 9* (5), 497–503.

Factors:	Environment type (virtual, real).
Computing platform:	SGI Onyx with twin 196-MHz MIPS R10000 processors, InfiniteReality graphics, 192 MB main memory.
Visual display:	VR4 HMD with resolution of 742 × 230 pixels per eye, FOV 67° diagonal at 85% overlap, 170,660 color elements. Frame rate ≥ 20 Hz. Latency ~ 120 ms.
Tracking:	Two Polhemus FASTRAKs for tracking head and mouse.
Navigation:	Move through environment in direction of gaze while pressing thumb button on 5-button, 3D mouse.
Object manipulation:	None.
Virtual world:	University research lab. Total scene 12,564 polygons.
Experimental task:	Search for a red box hidden in an office space. 7–14 min in the virtual office, 6–10 min in the real office.
Participants:	20 university students; 15 males.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 2.0, 6-item SUS questionnaire.
Task-related measures:	Subjective rating of task performance.
Performance measures:	Time to complete task.

Findings:
(1) Environment type had no significant relationship with PQ and SUS totals, but RE participants gave significantly higher scores for 2 SUS items.
(2) SUS questionnaire scores had no significant correlation with PQ Total scores for the virtual world but had a significant positive correlation for the real world condition.
(3) Task performance had no significant correlation with Witmer-Singer PQ scores or with SUS questionnaire scores.
(4) Self-rating of task performance had no significant correlation with SUS questionnaire and PQ scores.

[Usoh 1999] Usoh, M. K. A., Whitton, M. C., Bastos, R., Steed, A., Slater, M., and Brooks Jr., F. P. (1999). Walking > walking-in-place > flying in virtual environments. *Proceedings of the 26th Annual Conference on Computer Graphics and Interactive Techniques,* Los Angeles, USA, August, 359–364. See also Slater, M., and Usoh, M. (1993a). The influence of a virtual body on presence in immersive virtual environments. *Proceedings of the 3rd Annual Conference on Virtual Reality*, London, UK, April, 34–42.

Factors: Navigation (walking-in-place, push-button-fly, real walking).
Computing platform: SGI Onyx2 with 1 graphic pipe, four 195-MHz MIPS R10000 processors, 2 GB main memory. Scene rendered using Open GL and locally developed software.
Visual display: Virtual Research V8 HMD with (640 × 3) × 480 pixels per eye, FOV 60° diagonal at 100% overlap, aspect ratio 4:3. Radiosity lighting, texturing for half the polygons. Frame rate 30 Hz stereo. Overall system latency 100 ms.
Tracking: Custom optical wide area tracking, 10 × 4 m, latency 25 ms, head and one hand.
Navigation: For push-button-fly, used a joystick with locomotion in direction of gaze. Lag 500 ms for walking-in-place.
Object manipulation: Using joystick.
Virtual world: 5 × 4 m training room and 5 × 4 m pit room, connected by a door. Training room contained some chairs, a blue box, a green box. Pit room has 0.7-m ledge 6 m above the floor of the room, with a chair positioned on the ledge on the side of room opposite the door. Floor below populated with living room furniture. Self-representation as virtual body. Total 40,000 polygons.
Training: Participants practiced locomotion and picking up the blue box until they felt comfortable with both.
Experimental task: Pick up green box in training room and carry it to the chair in the pit room.
Participants: 44 participants; 28 males. 11 participants had VE prior experience.
Study design: Between-subjects.
Presence measures: 3-item SUS Questionnaire, 7-item SUS Questionnaire, behavioral presence questionnaire (covering reported indicator or awareness of background noises in lab, rating of the similarities between reaction when look down over pit versus expected real world reaction, rating of vertigo looking down over pit, rating of willingness to walk out over pit, path taken to chair).
Person-related meas.: Gender, game-playing experience.
Task-related measures: Degree of association with virtual body.
Findings:
(1) Real walkers gave significantly higher presence scores (on the 7-item SUS) than walking-in-place users, who reported significantly more presence than push-button-fliers. When oculomotor discomfort was considered, there was no significant difference between real walking and walking-in-place, but these groups reported significantly more presence than push-button-fliers. There was no significant difference for the expanded SUS Questionnaire.
(2) Navigation had no significant relationship with 3-item SUS scores or behavioral measures of presence.
(3) Degree of association with virtual body had a significant positive relationship with 3-item and 7-item SUS scores and behavioral presence.
(4) 3-item SUS scores had a significant positive correlation with behavioral measures of presence.

(5) Gender had a significant relationship with 3-item SUS scores, with females reporting more presence.
(6) Game playing had a significant negative relationship with 3-item and 7-item SUS scores but had no significant correlation with behavioral presence.

[Usoh 1996] Usoh, M., Alberto, C., and Slater, M. (1996). Usoh, M., Alberto, C., and Slater, M. (1996). *Presence: Experiments in the psychology of virtual environments*. University College London, UK, Department of Computer Science. Available:
http://www.cs.umu.se/kurser/TDBD12/VT07/articles/precense-paper-teap_full96.pdf

Factors:	Detail (realistic with colored and textured objects, monochrome objects with no texture), agents (people standing by desks, no people).
Computing platform:	Division's ProVision 100 system.
Visual display:	Flight Helmet HMD with 360 × 240 pixels per eye, FOV 75° H.
Tracking:	Head tracking.
Navigation:	Using mouse.
Object manipulation:	Touching computer with virtual hand.
Virtual world:	Laboratory in Computer Science Department (Room V127). Included accurate representation of color and placement of desks, chairs, computers, cabinets, and floor space. Virtual people in the form of cardboard cutouts.
Training:	Familiarization with virtual world by navigating through it.
Experimental task:	Move through virtual world and switch on 6 computers, being automatically transported back to starting position after each computer switched on. Then go back and touch computers previously switched on (without being transported after each touch).
Participants:	16 students and college staff. 8 participants had desks in Room V127, 8 unfamiliar with Room V127.
Study design:	Between-subjects.
Presence measures:	Multi-item questionnaire including 3 items related to presence. Observation of socially conditioned behaviors and conventions.
Person-related meas.:	NLP assessment.
Findings: (1)	Level of detail and agents had no significant relationship with observed behavior.
(2)	For participants unfamiliar with Room V127, auditory representation mode had a significant negative correlation with presence.

[Väljamae 2004] Väljamae, A., Larsson, P., Västfjäll, D., and Kleiner, M. (2004). Auditory presence, individualized head-related transfer functions, and illusory ego-motion in virtual environments. *Proceedings of the 7th Annual International Workshop on Presence*, Valencia, Spain, October, 252–258.

Factors:	HRTF (individualized, generic), sound rotation velocity (60, 20º per second), number concurrent sound sources (3, 1), distracters (present, absent).
Computing Platform:	HRTFs measurement system designed by Chalmers Room Acoustic Group.
Computing Platform:	Acoustic simulations rendered offline in CATT-Acoustic v8 using Walkthrough Convolver.
Visual display:	None.
Auditory display:	Beyerdynamic DT 990Pro circumaural headphones driven by a NAD Amplifier.
Tracking:	None.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Marketplace in Tübingen, Germany, with binaural simulations of a virtual listener standing in one place and rotating a certain number of laps. 3 still sound sources used were a bus on idle, a small fountain, and a barking dog. Participant seated on an ordinary chair placed on an electronically controllable turntable.
Training:	None.

Experimental task: Verbally report direction of motion.
Participants: 12 participants; 5 males; mean age 24 years. Normal hearing verified by a standard audiometric procedure.
Presence measures: 1-item rating.
Task-related measures: *Vection intensity rating, vection convincingness rating, count of ego-motion experiences*.
Findings:
(1) Individualized HRTFs were associated with significantly presence ratings.
(2) Velocity and number of sound sources had no significant relationship with presence.
(3) For single sound source condition only, significantly higher presence ratings were given when distracters were present.
(4) HRTFs and velocity had no significant relationship with vection intensity or convincingness. For sound sources, significantly more vection was reported for multiple sources.

[Viciana-Abad 2005] Viciana-Abad, R., Reyes-Lecuona, A., and Cañadas-Quesada, F. J. (2005). Difficulties using passive haptics augmentation in the interaction within a virtual environment. *Proceedings of the 8th International Workshop on Presence*, London, UK, September, 287–292.

Factors: Haptic passives (flat surface used, absent).
Visual display: IIS VR8 HMD.
Tracking: Ascension Technology's Flock of Birds and VTi Cyberglove for hand tracking; also head tracking.
Navigation: None.
Object manipulation: Using Cyberglove.
Virtual world: Simple world presenting a "Simon Says" device that has 4 differently colored buttons that light up in some order to form a sequence. Player has to repeat sequence. When player is correct, difficulty increases by adding an additional step to the sequence. When player is incorrect, an error sound is given, and two lateral plates come up the grab the player's hand. In passive haptic condition, a table in front of participant is registered with device image.
Training: Play "Simon Says" game for 2 min with no "hand grabbing."
Experimental task: Play "Simon Says" game for 4 min.
Participants: 18 undergraduates in 1st year telecommunication engineering courses; 10 males; age range 17 to 19.
Study design: Within-subjects.
Presence measures: SUS Questionnaire, Witmer-Singer PQ.
Task-related measures: *Estimation of how long trial lasted*.
Performance measures: *Game score (maximum number of steps achieved)*, *number of game errors*, *time between button pressings*.
Findings:
(1) Participants with passive haptic feedback gave significantly higher total PQ scores, also for Control/Involvement, Natural, Interface Quality, Auditory, and Haptics subscales. There was no significant difference in SUS Questionnaire scores.
(2) Participants without passive haptic feedback achieved significantly higher game scores.
(3) Passive haptic feedback had no significant relationship with average time between button pressings or estimates of time spent.

[Vinayagamoorthy 2004] Vinayagamoorthy, V., Brogni, A., Gillies, M., Slater, M., and Steed, A. (2004). An investigation of presence response across variations in visual realism. *Proceedings of the 7th Annual International Workshop on Presence*, Valencia, Spain, October, 148–155.

Factors: Texture quality (nonrepetitive, repetitive), character realism (texture-mapped face, cartoon-like).

Computing Platform:	Trimension ReaCTor Cave-like system using SG Onyx2 with eight 300-MHz R12000 MIPS processors and 4 InfiniteReality2 graphics pipes. DIVE and 3D Studio Max software, with the Platform Independent Architecture for Virtual Characters and Avatars (PIAVCA) for virtual character control.
Visual display:	Cave, with three 3 × 2.2 m walls and a 3 × 3 m floor, and CrystalEyes stereo glasses.
Navigation:	Using joystick.
Object manipulation:	None.
Virtual world:	An urban street lined with buildings and a few secondary streets. Textures (~ 40 or 20) used on billboards and fronts. 16 H-Anim compliant characters with animated walks moved up and down the street, with only 8 visible at any one time.
Training:	Training to understand BIPs concept. Practice moving in a virtual training room.
Experimental task:	After training, exit from training room on the street where told to do as the participant pleased for a few minutes. Signal "transitions to real" by pressing a button on the joystick. Returned to lab by leaving street through a door back to the training room.
Participants:	40 participants.
Study design:	Between-subjects.
Presence measures:	*1 item on presence*, BIPs, 5-item SUS Questionnaire, 6-item ITC-SOPI, HRV, *1 item on co-presence*.
Person-related meas.:	Computer game experience.
Task-related measures:	Perceived realism of street, perceived visual and behavioral realism of characters, perceived expressiveness of characters, level of reported interaction with characters.
Findings:	(1) Texture quality and character realism had a significant relationship with presence questionnaire scores. Also, texture quality and character realism had a significant interaction with less presence reported for repetitive textures combined with texture mapping.
	(2) Texture quality and character realism had no significant relationship with number of BIPs or changes in heart rate.
	(3) Perceived behavioral realism of characters had a significant positive association with presence.
	(4) Computer game experience had a significant positive association with presence questionnaire scores.
	(5) Adjusted number of BIPs had a significant negative association with presence questionnaire scores.
	(6) Perceived realism of street, perceived visual realism of characters, perceived expressiveness of characters, and level of reported interaction with characters had no significant association with presence questionnaire scores.
	(7) Number of BIPs had a significant negative association with change in heart rate.

[Vinayagamoorthy 2002 (1)] Vinayagomoorthy, V. (2002). *Bender behavior: Posture & emotion*. First Year Viva, University College London, (UCL), London, UK. See also Mortenson, J., Vinayagamoorthy, V., Slater, M., Steed, A., Lok, B., and Whitton, M. C. (2002). Collaboration in Tele-Immersive Environments. *Proceedings of the Workshop on Virtual Environments 2002,* Barcelona, Spain, May, 93–101.

Computing platform:	SG Onyx2 with eight 300-MHz R12000 MIPS processors, 8 GB RAM and 4 InfiniteReality2 graphics pipes for Trimension ReaCTor system. SG Onyx with twin 196-MHz MIPS R10000 processors, InfiniteReality graphics, and 192 MB main memory for HMD system. DIVE software. Systems connected over Internet2, with round-trip times ~ 80–90 ms.
Visual display:	Trimension ReaCTor with 3 × 2.2 m walls and 3 × 3 m floor, CrystalEyes stereo glasses, frame rate 45 Hz. Virtual Research V8 HMD, with 640 × 480 × 3 color elements/eye, FOV 60° diagonal at 100% overlap.

Tracking: Head and hand tracking using InterSense IS-900 with stereo glasses and UNC HiBall Tracker.
Navigation: Walking in actual space plus using hand-held 4-button joystick in ReaCTor system. Using 5-button joystick in HMD system.
Virtual world: Large open space with simple building in middle. Stretcher on ground outside building. Avatars represented as block-like structures with movable head and pointer indicating position of participant's tracked hand.
Training: Practice in navigating, lifting and carrying in a different virtual world to that used for the experimental task.
Experimental task: Meet with a partner (experimenter) and negotiate on lifting a stretcher together. Then carry stretcher along a blue path into a building and put it down on a red colored area inside the building. 5 to 8 min allowed, depending on stage reached. Experimenter behaved as either very happy or very depressed.
Participants: 19 students; 14 males; age range 19 to 34.
Study design: Between-subjects.
Presence measures: 6-item co-presence questionnaire.
Task-related measures: Assessment of self and partner's performance, rating of similarity of task to that in real life, ratings of harmony and cooperation between partners, *rating of partner's mood*.
Findings:
(1) Co-presence had a significant positive relationship with assessment of self performance and assessment of partner's performance.
(2) Co-presence had a significant positive relationship with rating of harmony.
(3) Co-presence had a significant positive relationship with rating of cooperation.
(4) Co-presence had a significant positive relationship with rating of similarity of task to real experience.
(5) Co-presence had a significant negative relationship with rating of how participant hindered other participant in carrying out the task.

[Vora 2002 (1)] Vora, J., Nair, S., Gramopadhye, A. K., Duchowski, A. T., Melloy, B. J., and Kanki, B. (2002). Using virtual reality technology for aircraft visual inspection training: Presence and comparison studies. *Applied Ergonomics, 33,* 559–570.

Factors: Training session.
Computing platform: SGI Onyx2 InfiniteReality System with 8 raster managers, 8 MIPS R12000 processors, 0.5-GB texture memory.
Visual display: Stereoscopic Virtual Research V8 HMD with 640 × 480 resolution.
Tracking: ISCAN binocular eye tracker mounted within HMD. Ascension Technology's Flock of Birds for head tracking, hand tracking.
Navigation: 6 DOF hand-held mouse.
Object manipulation: Using hand-held mouse that represented a virtual tool in the virtual world.
Virtual world: Aircraft cargo bay with texture maps taken from real cargo bay. 4 scenarios, such that 3 scenarios contained one type of defect (corrosion, crack, damaged conduits), and 4th had all three types of defect. Defects occurred at varying severity levels and locations. Scenarios presented with or without defects. Scenarios with defects included 12 defects.
Training: Shown real aft-cargo area of a wide-bodied aircraft at hangar site. Walkthrough of virtual cargo bay and provided with verbal description of defects, then practice with simulation. ~ 5 min.
Experimental task: For 4 scenarios, conduct a visual inspection of the cargo bay of an airplane, similar to one in the L1011 aircraft. Identify defects by using mouse to click on them. Moved on to next scenario when a participant believed he had identified all the defects (if any) in the current scenario. Limited to 20 min.
Participants: 14 undergraduate and graduate students; age range 20 to 30; 20/20 vision.
Study design: Within-subjects.
Presence measures: 20-item Witmer-Singer PQ.

Person-related meas.:		Witmer-Singer ITQ.
Findings:	(1)	Participants reported significant differences from the anchors values for 11 PQ items. PQ Involvement scores had a significant positive correlation with PQ Natural scores and PQ Interface Quality scores. PQ Natural scores had a significant positive correlation with PQ Interface Quality score.
	(2)	ITQ Involvement scores had a significant positive correlation with PQ Involvement scores.

[Wang 2006 (1)] Wang, S., Xiong, X., Xu, Y., Wang, C., Zhang, W., Dai, X., and Zhang, D. (2006). Face tracking as an augmented input in video games: enhancing presence, role playing, and control. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* Montreal, Quebec, Canada, April, 1097–1106.

Factors:		Motion-detection game (with face tracking, without face tracking).
Computing platform:		1.8-GHz Pentium laptop with ATI Technologies, Inc. Radeon 9800 and Universal Serial Bus (USB) webcam placed on computer monitor facing toward player. DirectShow for camera processing and DirectX 9.0 for graphics processing.
Visual display:		Laptop monitor.
Tracking:		Face tracking.
Navigation:		None.
Object manipulation:		Via face movement.
Virtual world:		Diver game where the player punches fish away from an oxygen mask super-imposed on his head to gain game points. Fish chase the diver while he moves. He can hit oxygen bottles with his head for more points, but winning points exposes the player to attacks. Event-driven emoticons are introduced into game to stimulate emotional responses. The player pushes away fish that swim too close, also adding to their game score. In addition to the base game, one version had no mask and emoticons. Another version had no face-tracking and no mask and emoticons.
Training:		Trial-and-error session, with players “thinking aloud” to uncover players’ under-standing of the game as novice players (supported by questionnaire and interview).
Experimental task:		Play game.
Participants:		36 participants; 32 males; age range 21 to 28; mean age 25 years. None familiar with camera-based games; all played video or computer games at least once a month. 18 rated themselves as veteran FPS players.
Presence measures:		Assessed based on performance data (hit rate, earned bonus) and movement data (accumulated horizontal head movement); assessed based on emotional responses (valence, arousal, joy, pleasant relaxation, depressed mood).
Task-related measures:		(See Presence measures above).
Performance measures:		(See Presence measures above).
Findings:	(1)	Participants gave significantly higher emotional responses for the use of face tracking (with mask and emoticons).
	(2)	Participants protected the attacked area significantly less when face tracking was not provided.
	(3)	Participants gained significantly more bonus points when face tracking (and mask and emoticons) was (were) provided.
	(4)	Participants accumulated significantly more horizontal movement when face tracking (and mask and emoticons) was (were) provided.
	(5)	Participants reported significantly more joy for face tracking with mask and emoticons than for face tracking alone.

[Wang 2006 (2)] Wang, S., Xiong, X., Xu, Y., Wang, C., Zhang, W., Dai, X., and Zhang, D. (2006). Face tracking as an augmented input in video games: enhancing presence, role playing, and control. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* Montreal, Quebec, Canada, April, 1097–1106.

Factors:		Motion-detection game (with face tracking, without face tracking).
Computing platform:		1.8-GHz Pentium laptop with ATI Technologies, Inc. Radeon 9800 and USB webcam placed on computer monitor facing toward player. DirectShow for camera processing and DirectX 9.0 for graphics processing.
Visual display:		Laptop monitor.
Tracking:		Face tracking.
Navigation:		USB game pad.
Object manipulation:		USB game pad.
Virtual world:		FPS Bullet Time game, where player physically dodges while undergoing attack and peeks to check out a hidden threat, where head movements are taken as reflecting intentions. Bullets are rendered with a trajectory that provides a visual hint for dodging.
Training:		Trial-and-error session with players “thinking aloud” to uncover players’ understanding of the game as novice players (supported by questionnaire and interview).
Experimental task:		Play game.
Participants:		36 participants; 32 males; age range 21 to 28; mean age 25 years. None familiar with camera-based games; all played video or computer games at least once a month. 18 rated themselves as veteran FPS players.
Presence measures:		ITC-SOPI. Assessed based on performance data (hit rate, earned bonus) and movement data (accumulated horizontal head movement); assessed based on emotional responses (valence, arousal, joy, pleasant relaxation, depressed mood).
Task-related measures:		(See Presence measures above).
Performance measures:		(See Presence measures above).
Findings:	(1)	Players reported significantly higher ITC-SOPI scores for “I am in the game scene” and “I am involved in the game” for the use of face tracking.
	(2)	Use of face tracking had no significant association with upper body sideways movement.
	(3)	Use of face tracking had no significant association with player performance.

[Waterworth 2001] Waterworth, E., Waterworth, J., Holmgren, J., Rimbark, T., and Lauria, R. (2001). The illusion of being present: Using the interactive tent to create immersive experiences. *Proceedings of the 4th Annual International Workshop on Presence,* Philadelphia, USA, May.

Factors:	Film content (concrete, abstract).
Visual display:	Interactive Tent with domed projection screen above prone participant.
Audio display:	3D sound.
Tracking:	Head position and body movement.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Illusion of Being designed to transport participant between states of excitement and calmness and between modes of presentation that elicit thought or direct sensory experiences. Taken through cycles of elements: snow, fire, earth, water. Moving head up or down for experience in a more concrete, perceptual, or abstract version. Moving head right or left determines whether what is experienced is captured from reality or is purely synthetic. Four versions: (1) filmed events with natural soundtrack; (2) text, sketches, and spoken words describing events; (3) detailed virtual world with synthesized sounds; and (4) wireframe 3D with text labels and stylized synthetic sound effects.

Experimental task:		View 4 sets of 4 film clips of different durations (23, 50, 77, 104 sec).
Participants:		16 students; 15 males; age range 20 to 40.
Study design:		Within-subjects.
Presence measures:		8-item IPQ.
Task-related measures:		Estimation of film duration.
Findings:	(1)	Concrete content was associated with significantly higher presence scores.
	(2)	Film content had a significant correlation with presence only for 1 of 4 films (wireframe).
	(3)	*Film content had no relationship with duration.*

[Welch 1999] Welch, R. B. (1999). How can we determine if the sense of presence affects task performance? *Presence, 8* (5), 574–577.

Factors:		Audio cues (screeching of tires, no cues).
Visual display:		HMD.
Experimental task:		Control a virtual car and attempt to collide with various cubes while avoiding others.
Study design:		Within-subjects.
Presence measures:		Presence rating scale (1–100%).
Performance measures:		*Number of collisions with cubes in a fixed period of time.*
Findings:	(1)	Sound of tires was associated with significantly higher presence ratings.
	(2)	*Audio cues had no significant relationship with task performance*.

[Welch 1996 (1)] Welch, R. B., Blackmon, T. T., Liu, A., Mellers, B. A., and Stark, L. W. (1996). The effects of pictorial realism, delay of visual feedback, and observer interactivity on the subjective sense of presence. *Presence, 5* (3), 263–273.

Factors:		Scene realism (high scene detail, low scene detail), level of interaction (driver, passenger).
Computing platform:		SGI 4D/120 GTXB graphics workstation.
Visual display:		Monitor with horizontal GFOV 62.5°, 1280 × 1024 pixels, stereoscopic viewing using StereoGraphics Corporation CrystalEyes shutter glasses. Nominal IPD 6.5 cm. Subject seated with viewing distance of 0.75 m, FOV ~ 27°. Curtain drawn around subject for isolation from rest of laboratory.
Navigation:		Steering wheel and foot-operated accelerator and brake pedals to control the car's direction and speed.
Object manipulation:		None.
Virtual world:		In high-realism condition, blue sky, hilly road surface and surround, green background, red farm houses, oncoming cars, and guard posts. In low-realism condition, black sky, flat road surface and surround, black background, no peripheral objects, no oncoming cars.
Training:		Two pairs of practice runs.
Experimental task:		Drive a simulated car as quickly and smoothly as possible through a lap of a winding road. When passenger instead of driver, count number of oncoming cars.
Participants:		Working in pairs, 20 optometry students, laboratory staff, and engineering graduate students; 9 males; mean age 27.2 years.
Study design:		Within-subjects.
Presence measures:		Paired comparison with rating of difference.
Findings:	(1)	Scene realism and level of interaction had a significant interaction, such that more presence was reported for the high scene detail/driver condition than for the low scene detail/passenger condition.

[Welch 1996 (2)] Welch, R. B., Blackmon, T. T., Liu, A., Mellers, B. A., and Stark, L. W. (1996). The effects of pictorial realism, delay of visual feedback, and observer interactivity on the subjective sense of presence. *Presence, 5* (3), 263–273.

Factors:		Scene realism (high scene detail, low scene detail), latency (no additional delay, additional 1.5-sec delay in visual feedback). (Standard delay 200–220 ms.)
Visual display…		
Presence measures:		As in [Welch 1996 (1)], except for Participants: 20 optometry students, laboratory staff, engineering graduate students; 9 males; mean age 23.4 years.
Findings:	(1)	Scene realism and latency had a significant interaction, such that more presence was reported for high scene detail/no additional delay condition than for the low scene detail/additional delay condition.

[Whitelock 2000 (1)] Whitelock, D., Romano, D., Jelfs, A., and Brna, P. (December 2000). Perfect presence: What does this mean for the design of virtual learning environments? *Education and Information Technologies, 5* (4), 277–289. See also Whitelock, D., and Jelfs, A.(2000). Vulnerable viewers of valid vistas? Assessing student performance when the perception of presence is increased in a virtual learning environments. *Proceedings of the 3rd Annual International Workshop on Presence,* Techniek Museum, Delft, The Netherlands, March.

Factors:		Audio cues (present, absent).
Computing platform:		PC-based. MTropolis software.
Visual display:		Desktop monitor showing 2 views: one from submarine, other plan view showing where submarine located.
Navigation:		Standard mouse used to move the submarine.
Virtual world:		Representation of the North Atlantic Ridge. Supported with movies of geological features, flora, and fauna that illustrate probe functions.
Training:		Either viewed prerecorded video of using application or read script containing same instructions used in the video. 30-min time limit.
Experimental task:		Travel in submarine to the Ridge at the bottom of the ocean and explore the terrain for geological structures and biological life in seven major locations. 30-min time limit.
Participants:		10 pairs of high school students; age range 16 to 17.
Study design:		Between-subjects.
Presence measures:		3-item presence questionnaire.
Task-related measures:		Rating of ease of task.
Performance measures:		*Pre- and post-test of learning*.
Findings:	(1)	Use of audio cues was associated with significantly higher presence scores.
	(2)	Ease of task had a positive correlation with presence.
	(3)	*Audio cues had no significant relationship with conceptual learning.*

[Wideström 2000] Wideström, J., Axelsson, A.-S., Schroeder, R., Nilsson, A., Heldal, I., and Aeblin, Å. (2000). The collaborative cube puzzle: A comparison of virtual and real environments. *Proceedings of the 3rd International Conference on Collaborative Virtual Environments,* San Francisco, USA, September, 165–171.

Factors:	Display type (real, 5-sided Cave display, desktop).
Computing platform:	SGI Onyx2 InfiniteReality with fourteen 250-MHz MIPS R10000 processors, 2 GB RAM, 3 graphics pipes. SGI O2 with 1 MIPS R10000 processor, 256 MB RAM. dVise 6.0 software with SGI Performer renderer. Lake Huron 3.0 for audio.
Visual display:	3 × 3 × 3 m TAN 3D Cube with projection on 5 walls (no ceiling), stereoscopic viewing using StereoGraphics Corporation CrystalEyes shutter glasses; frame rate at least 30 Hz. 19-in. monitor with frame rate at least 20 Hz.

Auditory display:	Using headsets.
Tracking:	Polhemus trackers attached to shutter glasses and hand.
Navigation:	In the Cave system: by moving around and gesturing with dVise 3D mouse. In the desktop system: by moving middle button on standard 2D mouse.
Object manipulation:	In the Cave system: blocks selected and moved by participant putting his hand into a virtual cube and pressing on a 3D mouse button. In the desktop system: blocks selected by clicking on the block with the left button of 2D mouse, then moved by keeping right button pressed and moving the mouse; cubes rotated using a combination of the right mouse button and shift key.
Virtual world:	Empty room containing 8 blocks with 1 of 6 different colors on each side. Representation of self and participant using standard dVise avatars.
Experimental task:	Two participants cooperate to solve a puzzle by arranging blocks into a cube, such that each side of the completed cube displays a single color. 20-min time limit.
Participants:	44 pairs of participants; 53 males; age range 20 to 56; mean age 32 years.
Study design:	Within-subjects.
Presence measures:	2-item presence questionnaire, 2-item co-presence questionnaire.
Task-related measures:	*3-item contribution to task questionnaire, 1 item on collaboration*.
Findings: (1)	Cave participants gave significantly higher presence scores.
(2)	Display type had no significant relationship with co-presence.
(3)	Presence had a significant correlation with co-presence only in the desktop environment.
(4)	*All participants reported that Cave participants contributed significantly more to the task.*
(5)	*Participants in the real condition gave significantly higher ratings for collaboration than VE participants. There was no significant difference in ratings between Cave display and desktop conditions.*
(6)	*There was a significant order effect on collaboration score, such that participants with experience from the virtual task reported significantly more collaboration in the real world than in the virtual world, while there was no difference for participants who started with the real task and then performed the virtual task.*

[Wiederhold 2001] Wiederhold, B. K., Jang, D. P., Kaneda, M., Cabral, I., Lurie, Y., May, T., Kim, I. Y., Wiederhold, M. D., and. Kim, S. I. (2002). An investigation into physiological responses in virtual environments: An objective measurement of presence. In G. Riva and C. Galimberti (Eds.), *Towards cyberpsychology: Mind, cognitions, and society in the internet age* (pp. 175–183). Amsterdam: IOS Press.

Computing platform:	Intel microprocessor-based PC, with advanced audio and Diamond Monster 3D graphics cards. Customized software.
Visual display:	Liquid Image MRG4 HMD. Subject seated.
Audio display:	Earphones on HMD, with vibratory sensations delivered by subwoofer mounted under chair.
Tracking:	Polhemus InsideTrak for head tracking.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Passenger cabin in an airplane with outside graphics.
Training:	None.
Experimental task:	View airplane flight as passenger seated in left window seat over wing and looking out the left window. 6-min flight.
Participants:	72 computer expo attendees; 30 males; age range 18 to 73; mean age 36.4 years. 10 phobic participants, based on the DSM-IV criteria.
Presence measures:	Reality Judgment and Presence Questionnaire, %Δskin resistance and %Δheart rate.
Person-related meas.:	TAS, DES.
Task-related measures:	*Kennedy SSQ*.

Findings:	(1)	Presence had a significant positive correlation with realism, TAS, and DES. Realism also had a significant positive correlation with TAS and DES.
	(2)	Percentage Δskin resistance and Δheart rate had a significant negative correlation with presence.
	(3)	*SSQ score had a significant correlation with the DES but not with the TAS*.

[Wiederhold 1998] Wiederhold, B. K., Davis, R., and Wiederhold, M. D. (1998). The effects of immersiveness on physiology. In G. Riva et al. (Eds.), *Virtual environments in clinical psychology and neuroscience* (pp. 52–60). Amsterdam: IOS Press.

Factors:	Visual display (HMD, 3D monitor).
Computing platform:	Intel microprocessor-based PC, with advanced audio and Diamond Monster 3D graphic cards. Software from Previ (Spain), VRHealth (Italy), Hanyang University (Seoul, South Korea), and Virtually Better.
Visual display:	Liquid Crystal MRG4 HMD. Subject seated.
Audio display:	HMD headphones or speakers positioned next to monitor. Subwoofer mounted under participant's chair.
Tracking:	Polhemus InsideTrak for head tracking.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Passenger cabin in an airplane with outside graphics.
Experimental task:	View airplane flight as passenger seated in left window seat over wing and looking out the left window. 10-min flight.
Participants:	5 psychology doctoral-level students; 2 males; age range late 20s to 40s. No prior experience with VE. One participant had a fear of flying, meeting DSM-IV criteria for a specific phobia.
Study design:	Within-subjects.
Presence measures:	Δskin resistance, Δheart rate, Δperipheral skin temperature, Δrespiration rate.
Findings: (1)	For nonphobic participants, the HMD was associated with significantly lower skin resistance.
(2)	For nonphobic participants, visual display had no significant relationship with Δheart rate, Δperipheral skin temperature, and Δrespiration rate.

[Wilfred 2004] Wilfred, L. M. (2004). *Learning in affectively intense virtual environments*. Master's thesis, University of Missouri – Rolla, MO.

Factors:	Affective intensity (intense, neutral).
Computing platform:	2.8-GHz Pentium 4 with 512 MB RAM. Virtual worlds developed using Half-Life game engine. Bopiac system to collect physiological data.
Visual display:	i-glasses SVGA 3D HMD.
Tracking:	None.
Navigation:	Using 5-button mouse.
Object manipulation:	Using 5-button mouse.
Virtual world:	Two versions: one affectively intense and the other affectively neutral. Representation of computer science building at University of Missouri – Rolla. Intense world had explosions and fires starting randomly (within 0 to 25 sec of each other) around the participants' avatar. Both versions had dead and injured bodies generated randomly at 18 locations.
Training:	Conducted in two connected virtual rooms: one containing a fire extinguisher and the other a fire. Used to gain familiarity with interface and controls.
Experimental task:	As first responder fire fighter, complete an inspection of the building to locate the dead and injured, while dealing with any situations that arose. 12 min. Then in real building, with audio tape replaying sounds of fires and explosions, locate rooms

where dead and injured had been and make a note of these. Possible actions included setting off a fire alarm, picking up a fire extinguisher, putting out a fire.

Participants: 22 undergraduates.
Study design: Between-subjects.
Presence measures: 5-item SUS Questionnaire.
Person-related meas.: Gender, Affective Intensity questionnaire, ITQ.
Task-related measures: Δskin conductance.
Performance measures: Count of dead and injured people.
Findings:
(1) Affective intensity had no significant relationship with presence or Δskin conductance. Participants' affective intensity had no significant correlation with presence or Δskin conductance.
(2) ITQ Games subscale had a significant positive correlation with presence but not with Δskin conductance.
(3) Gender had no significant correlation with either presence or Δskin conductance.
(4) Task performance had no significant correlation with either presence or Δskin conductance.
(5) Task performance had no significant correlation with participants' affective intensity. It had a significant interaction with gender only for the count of injured, with males performing better.

[Witmer 1998 (2)] Witmer, B. G., and Kline, P. B. (1998). Judging perceived and traversed distance in virtual environments. *Presence, 7* (2), 144–167.

Factors: Navigation (treadmill, joystick, passive teleportation), gender, distance cues (auditory tone every 10 ft for every other segment, no cues), movement speed (1.2, 2.4 mph), texture density (2-ft, 4-ft tiles), traversed distance (10, 40, 80, 120, 160, 200, 240, 280 ft).
Computing platform: SGI Crimson Reality Engine. VE modeled using Software Systems MultiGen and rendered using SGI Performer.
Visual display: Fakespace Labs BOOM2C display fitted to participant's head using a head strap, used in monochrome mode, stereoscopic with 1280 × 1024 pixels per eye with 70° overlap, maximum FOV 140° H × 90° V.
Tracking: Via BOOM2C.
Navigation: Only forward movement permitted. Movement via treadmill, joystick, or by being passively teleported by the experimenter.
Object manipulation: None.
Virtual world: Four test routes, each consisting of a series of 8 connected hallway segments. Hallways 10 ft wide, 10 ft high, varied in length (20, 50, 90, 130, 170, 210, 250, 290 ft). Total length always 1210 ft. Segments formed right angles with each other to form alternating series of left-right turns.
Training: Follow a practice route in the VE twice, practicing procedures and movement (latter at two speeds).
Experimental task: Traverse 4 test routes, reporting traversed distance and time taken for each segment.
Participants: 72 university students; 36 males; age < 37 years.
Study design: Within-subjects for movement speed, texture density, and traversed distance, between-subjects for type of navigation, gender, and distance cues.
Presence measures: 32-item Witmer-Singer PQ Version 2.0.
Person-related meas.: Gender.
Task-related measures: *Rating of compellingness of movement*.
Performance measures: *Accuracy of estimates of distance traveled, relative error for each segment/route*.
Findings:
(1) Use of the treadmill was associated with significantly higher presence scores than those given for joystick use or teleporting.
(2) Gender had no significant relationship with presence.
(3) Distance cues had no significant relationship with presence.

(4) *Distance cues, movement speed, traversed distance, and 3 interactions (distance cues and movement speed, distance cues and traversed distance, movement speed and traverse distance) had a significant relationship with estimates of segment distance traveled and relative error. Type of movement, texture density, and gender had no relationship.*
(5) *Distance cues, movement speed and gender had a significant relationship with estimates of total route distance. Type of movement had no relationship.*
(6) *Use of the treadmill was associated with significantly higher ratings of compellingness than were given for joystick use, and both these were significantly higher than ratings given for teleporting.*

[Witmer 1996] Witmer, B. G., Bailey, J. H., and Knerr, B. W. (1996). Virtual spaces and real world places: Transfer of route knowledge. *International Journal of Human-Computer Studies*, *45,* 413–428. See also Bailey, J. H., and Witmer, B. G. (1994). Learning and transfer of spatial knowledge in a virtual environment. *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting,* Nashville, USA, October, 1158–1162.

Factors: Training type (RE, VE, verbal directions and photographs).
Computing platform: SGI Crimson Reality Engine with single processor, 2 raster managers. Model generated using Software Systems MultiGen, rendered using Sense8 Corporation. WorldToolKit.
Visual display: Stereoscopic, 2-color Fakespace Lab BOOM2C with FOV 140° H × 90° V, 1280 × 492 pixels per eye. Update rate 30–60 Hz.
Tracking: Head tracking using BOOM2C display.
Navigation: Using BOOM2C display, user moves in direction facing, or backwards, at a constant speed by depressing buttons on display control handles.
Object manipulation: None.
Virtual world: Large, spatially complex office building. Texture maps derived from photographs of objects.
Training: None.
Experimental task: 15-min study of route directions and photographs of landmarks for a complex route, either with or without a map. Then 3 rehearsals of route in the VE, in the actual building, or verbally. All participants required to stop at and identify 6 destinations along the route. All participants tested in actual building. Office building approximately 117,950 ft^2. Complex route (1,500 ft) wound along corridors on 3 floors leading to 6 destinations in 2 office suites; 41 directional changes and 47 two-choice decision areas along route. Building areas included typical office furnishings, including fluorescent lights, wall paintings, and exit signs. Model included functional staircases and out-of-the-window views. Doors to accessible areas automatically opened when approached.
Participants: 20 participants; 10 males.
Presence measures: 32-item Witmer-Singer PQ Version 2.0.
Person-related meas.: *29-item Witmer-Singer ITQ Version 2.0, gender.*
Task-related measures: Kennedy SSQ.
Performance measures: Route knowledge assessed using number of attempted wrong turns, route traversal time, misidentified destinations, distance traveled. Building configuration knowledge measured using a target triangulation technique (projective convergence providing consistency, accuracy, average distance error, and average miss distance measures).
Findings:
(1) Route knowledge and configuration knowledge had no significant correlation with presence.
(2) Simulator sickness had a significant negative correlation with presence.
(3) *During route rehearsal, type of rehearsal had a significant relationship with route learning, with slower route traversal times and more wrong turns for VE group than for other two groups, which were not significantly different.*

(4) During route rehearsal, trial had a significant negative relationship with route traversal time. Trial also had a significant interaction with type of rehearsal, such that the VE group showed a steeper learning curve with respect to route rehearsal time than the other two groups and, with respect to wrong turns, also a steeper learning curve than the symbolic group, which was steeper than that of the real group.
(5) For training transfer, type of rehearsal had a significant relationship with route learning, with the real group making fewer wrong turns than the VE group, who made fewer wrong turns and took less time than the symbolic group.
(6) For training transfer, type of rehearsal had a significant relationship with route traversal time, with those in the real and VE groups taking less time than those in the symbolic group.
(7) Type of rehearsal had no significant relationship with configuration knowledge.
(8) Configuration knowledge, as measured by accuracy and consistency on paper-based convergence test, had a significant negative correlation with ITQ scores.
(9) Gender had a significant association with configuration knowledge, with improved performance found for male participants.
(10) SSQ scores had no significant association with route or configuration knowledge.
(11) Gender had no significant association with SSQ scores.

[Witmer 1994a (1)] Witmer, B. G., and Singer, M. J. (October 1994). *Measuring presence in virtual environments* (ARI Technical Report 1014). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. See also Lampton, D. R., Knerr, B. W., Goldberg, S. L., Bliss, J. P., Moshell, M. J., and Blau, B. S. (1995). *The virtual environment performance assessment battery: Development and evaluation* (ARI Technical Report 1029). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Computing platform:	Two 486-MHz/DX50 PCs with Intel Action Media graphics boards. VE developed using Sense8 Corporation WorldToolKit.
Visual display:	Stereoscopic, color Virtual Research Flight Helmet HMD with FOV 83° H × 41° V, resolution 234 × 238 pixels per eye.
Tracking:	Polhemus ISOTRAK for head tracking.
Navigation:	Using joystick or spaceball.
Object manipulation:	Using joystick or spaceball.
Virtual world:	VEPAB VE, see [Singer 1995].
Training:	Explanation and demonstration of operation of control device.
Experimental task:	Set of generic VEPAB tasks: Snellen Chart, color perception test, distance estimation, backing-up, hallway turns, figure 8 hallway, doorways.
Participants:	24 participants; 16 males; age range 17 to 37; mean age 24 years.
Presence measures:	32-item Witmer-Singer PQ Version 1.0. Measured after each of the two experimental sessions.
Person-related meas.:	29-item Witmer-Singer ITQ Version 1.0.
Task-related measures:	Kennedy SSQ.
Performance measures:	Time to complete and accuracy of response to each task.

Findings:

(1) Accuracy for the windows task had a significant negative correlation with PQ Total and Control Responsiveness, Interface Awareness, and Control Distraction subscales. Accuracy for the bins task had a significant positive correlation with PQ Total and Control Responsiveness, Involvement, and Control Distraction subscales. Accuracy for the slide task had a significant positive correlation with PQ Total and Control Responsiveness, Sensory Exploration, and Involvement subscales. Accuracy for the dial task had a significant positive correlation with PQ Control Responsiveness and Involvement subscales. Accuracy for the choice reaction time task had no correlation with PQ Total or any subscales.
(2) Time to complete for the windows task had a significant negative correlation with PQ Total and Control Responsiveness, Interface Awareness, and Control Distrac-

tion subscales. Time for the bins task had a significant negative correlation with PQ Total and Control Responsiveness, Involvement, and Control Distraction subscales. Time for the slide task had a significant negative correlation with PQ Total and all subscales. Time for the dial task had a significant negative correlation with PQ Involvement subscale. Time for the choice reaction task had a significant negative correlation with PQ Total and Control Responsiveness, Sensory Exploration, and Involvement subscales. Time for the simple reaction time task had a significant negative correlation with PQ Total and Control Responsiveness, Sensory Exploration, and Involvement subscales.

(3) SSQ Total and all subscales had a significant negative correlation with PQ Control Responsiveness subscale.

(4) PQ scores had no significant correlation with ITQ scores.

(5) Performance had no significant correlation with ITQ Total.

[Witmer 1994a (2)] Witmer, B. G., and Singer, M. J. (October 1994). *Measuring presence in virtual environments* (ARI Technical Report 1014). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Computing platform…

Training: As in [Witmer 1994a (1)].

Experimental task: Set of generic VEPAB tasks: flying-thru-windows, elevator, bins, slide/dial manipulation, simple/choice reaction time, stationary/moving target acquisition.

Participants…

Performance measures: As in [Witmer 1994a (1)].

Findings:

(1) Accuracy for the windows task had a significant negative correlation with PQ Total and Control Responsiveness subscale. Accuracy for the bins task had a significant positive correlation with PQ Sensory Exploration and Involvement subscales. Accuracy for the slide task had a significant positive correlation with PQ Total and Control Responsiveness and Sensory Exploration subscales. Accuracy for the dial task had a significant positive correlation with PQ Sensory Exploration and Involvement subscales. Accuracy for the choice reaction task had a significant positive correlation with PQ Total and the Sensory Exploration subscale.

(2) Time to complete the windows task had a significant negative correlation with PQ Total and Control Responsiveness and Interface Awareness subscales. Time to complete the bins task had no significant correlation with PQ Total or any subscales. Time for the slide task had a significant negative correlation with PQ Total and Sensory Exploration subscale. Time for the dial and choice reaction tasks had no significant correlations with PQ Total or any subscales. Time for the simple reaction task had significant negative correlation with PQ Involvement subscale.

(3) SSQ Total had a significant negative correlation with PQ Total and Control Responsiveness, Sensory Exploration, and Involvement subscales. SSQ Nausea, Oculomotor, and Disorientation subscales had a significant negative correlation with PQ Control Responsiveness subscale. SSQ Nausea subscale had a significant negative correlation with PQ Sensory Exploration subscale. SSQ Oculomotor subscale had a significant negative correlation with PQ Involvement and Control Distraction subscales.

(4) PQ scores had no significant correlation with ITQ scores.

(5) Performance had no significant correlation with ITQ Total.

[Witmer 1994b (1)] Witmer, B. G., Bailey, J. H., and Knerr, B. W. (April 1994). *Training dismounted soldiers in virtual environments: Route learning and transfer* (ARI Technical Report 1022). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors: Training type (VE, building, symbolic), map (present, absent).

Computing platform:	SG Crimson Reality Engine. Multigen by Software Systems and WorldToolKit by Sense8 Corporation.
Visual display:	Fakespace Lab 2-color Boom2C display.
Audio display:	None.
Tracking:	Via Boom2C display.
Navigation:	Via Boom2C display.
Object manipulation:	None.
Virtual world:	Representation of first 3 floors of a building in the Central Florida Research Park, ~ 117,950 ft^2. Many of the office furnishings were included in offices and work spaces. Doors to modeled areas opened automatically when within 10 ft distance, and remained open for several seconds.
Experimental task:	Study of designated route for 15 min using step-by-step directions, landmark and destination photos and depending on condition, map with route marked. Followed by 3 route rehearsals in appropriate condition. Performance evaluated in a real-world transfer test, following the learned route and identifying 6 specified destinations along the route. Then participant taken to the lobby on third floor and asked to exit the building as quickly as possible using the most direct route. Third task required estimating direction and distance to 4 goal locations.
Participants:	60 college students; age range 18 to 53.
Study design:	Between-subjects.
Presence measures:	Witmer-Singer PQ.
Person-related meas.:	*Gender*.
Task-related measures:	Kennedy SSQ.
Performance measures:	Number of wrong turns, number of misidentified destinations, time to reach each destination and entire route, number of steps taken along route. Also, time taken and distance traveled to exit building, and, for location task, consistency, accuracy, average distance error, average miss distance.

Findings:

(1) Measures of route learning had no significant correlation with presence.
(2) Measures of configuration knowledge had no significant correlation with presence.
(3) SSQ scores had a significant negative correlation with presence.
(4) Training type had a significant relationship with route learning, with best performance for building training, followed by VE training, with symbolic training worst. Map and gender had no significant relationship with route learning.
(5) Training type and map had no significant main effect for configuration knowledge. There was an interaction with gender, such that males performed significantly better than females.

[Youngblut 2004 (1)] Youngblut, C. (2004). *Experience of presence in virtual environments* (IDA Document D-2960). Alexandria, VA: Institute for Defense Analyses.

Factors:	Visual display (rear projection screen, desktop, written procedures only).
Computing platform:	700-MHz Pentium III PCs, with NVIDIA GeForce 3 graphics accelerators. Reality by Design, Inc. CHEM-BIO SVS2 software developed using SimStorm.
Visual display:	Proxima 9260 rear projector with 9.5 × 7.5 ft. Da-Lite projection screen, enclosed in curtained-off area.
Audio display:	Voice-activated radios for team communication; speakers for sounds of alarms.
Tracking:	Tracking of head (vertical motion only) and mock chembio monitor using InterSense IS-600 Series Precision Motor Trackers.
Navigation:	Using belt-mounted, custom 3D joystick with rear-projection-screen interface, table positioned Microsoft Sidewinder Precision Pro 6 DOF joystick with desktop interface.
Object manipulation:	Using joystick controls and mock-up chembio monitor.
Virtual world:	Three of IDA's Virtual Cities with sub-meter accuracy. One was a re-creation of a warehouse on New York Pier 16, another was an office building in New York, and

		the third was Penn Station. All re-creations included representative objects. No self-representation.
Training:		25-min study of written procedures, followed with 5-min question-and-answer period. Participants in each VE group then received 10-min demonstration and practice of the immersive or desktop interface.
Experimental task:		VE participants also performed 2 practice missions to learn mission procedures for searching for chembio hazards in a designated area. 20 min each. Performance evaluated in a real-world transfer test, 30-min time limit.
Participants:		35 student intern employees; 27 males; mean age 21 years.
Study design:		Between-subjects.
Presence measures:		32-item Witmer-Singer PQ Version 1.0, 6-item SUS questionnaire.
Person-related meas.:		29-item Witmer-Singer ITQ Version 1.0, gender, game experience, experience with immersive VEs, Ekstrom's cognitive tests (visualization aptitude using Paper Folding test, spatial orientation using Card Rotation and Cube Comparison tests, visual memory using Map Memory test, spatial scanning using Map Planning test).
Performance measures:		Sum of correctness and completeness scores for individual elements of mission procedures.
Findings:	(1)	Visual display had no significant relationship with presence, as measured using either the PQ or SUS Questionnaire (traditional or modified method of scoring).
	(2)	For rear-projection-screen participants, PQ Total and PQ Involved/Control and PQ Natural subscale scores had a significant positive correlation with SUS Questionnaire scores (modified method). For desktop-monitor participants, PQ Natural subscale scores had a significant positive correlation with SUS Questionnaire scores (traditional method). There was a significant positive correlation between the two methods of scoring the SUS Questionnaire for desktop-monitor participants only.
	(3)	For rear-projection-screen participants, game experience and VE experience had a significant positive correlation with SUS Questionnaire scores (traditional). Spatial orientation (card rotations) also had significant positive relationships with PQ Total and PQ Involved/Control and PQ Interface Quality subscale scores. ITQ Involvement subscale had a significant negative correlation with PQ Interface Quality subscale. Gender, visualization aptitude, spatial orientation (cube comparisons), visual memory, and spatial scanning ability had no relationship with PQ or SUS scores.
	(4)	For desktop-monitor participants, spatial scanning and spatial orientation (cube comparisons) had a significant positive correlation with PQ Involved/Control subscale scores, and visual memory had a significant positive correlation with PQ Interface Quality subscale scores. For these participants, there were also significant positive relationships between ITQ (Total and all subscale scores) and the SUS Questionnaire (both traditional and modified). Gender, computer game experience, experience with immersive VEs, visualization aptitude, and spatial orientation (card rotations) had no relationship with PQ or SUS scores.
	(5)	For both VE groups together, SUS questionnaire scores (traditional method) had a significant positive correlation with performance. PQ scores had no correlation with performance.
	(6)	*Participants in VE groups achieved significantly higher mission scores.*

[Youngblut 2004 (2)] Youngblut, C. (2004). *Experience of presence in virtual environments* (IDA Document D-2960). Alexandria, VA: Institute for Defense Analyses.

Factors:	Visual display (rear projection screen, desktop, paper based).
Computing platform:	700-MHz Pentium III PCs, with NVIDIA GeForce 3 graphics accelerators. Reality by Design, Inc. CHEM-BIO SVS2 software developed using SimStorm.

Visual display:	Proxima 9260 rear projector with 9.5 × 7.5 ft Da-Lite projection screen, enclosed in curtained-off area.
Audio display:	None.
Tracking:	Tracking of head (vertical motion only) using InterSense IS-600 Series Precision Motor Tracker.
Navigation:	Using belt-mounted, custom 3D joystick with rear-projection-screen interface, table positioned Microsoft Sidewinder Precision Pro 6 DOF joystick with desktop interface.
Object manipulation:	Using joystick controls.
Virtual world:	Representation of the ground floor of an office building. This space was divided into 12 exterior offices, 4 interior offices, 2 small open areas, and 2 large open areas, 1 of which contained another office. There were two exterior entrance doors to the building and two stairwells providing access to upper floors. The space was empty except for eight objects. These objects were items of furniture, such as a desk, file cabinet, sofa, and snack machine. Six objects were positioned in offices, and the remaining two objects were positioned in the open areas.
Training:	Participants in each VE group received 1-min demonstration and practice of the immersive or desktop interface.
Experimental task:	Navigate freely through the office space to build spatial knowledge of the area. Three sessions of 4-min study of paper-based floor plan followed by 12-min of virtual world navigation for the rear-projection-screen and desktop participants.
Participants:	35 student intern employees; 21 males; mean age 21 years.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 1.0, 6-item SUS questionnaire.
Person-related meas.:	29-item Witmer-Singer ITQ Version 1.0, gender, experience with video games and 3D computer games, experience with immersive VEs, Ekstrom's cognitive tests (visualization aptitude using Paper Folding test, spatial orientation using Card Rotation and Cube Comparison tests, visual memory using Map Memory test, spatial scanning using Map Planning test).
Performance measures:	Distance and orientation to specific objects and room placement test immediately following third session. Room placement test repeated as retention test 1 week later.

Findings:

(1) Visual display had no significant relationship with presence, using either the PQ or SUS Questionnaire.

(2) PQ and SUS Questionnaires results (scored both in the traditional and modified manner) showed a significant positive correlation for desktop-monitor participants only. For desktop-monitor participants, there was a significant positive correlation between the two methods of scoring the SUS Questionnaire.

(3) For rear-projection-screen participants, SUS Questionnaire scores (traditional and modified methods) showed a significant correlation with gender, with females reporting a greater sense of presence. For these participants, there was also a significant positive correlation between PQ Interface Quality subscale and spatial orientation (card rotations) and PQ Interface Quality subscale and visual memory and a significant negative correlation between ITQ Total and ITQ Focus, and ITQ Involvement subscale scores and SUS Questionnaire scores (traditional) and between ITQ Focus subscale scores and SUS Questionnaire scores (modified method). Computer game experience, experience with VEs, visualization aptitude, spatial orientation (cube comparisons), and spatial scanning ability had no relationship with PQ or SUS scores.

(4) For desktop-monitor participants, there was also a significant negative relationship between SUS Questionnaire scores (traditional) and spatial orientation (cube comparisons). ITQ scores, gender, experience with games, experience with immersive VEs, (visualization aptitude, spatial orientation (card rotations)), visual memory, and spatial scanning had no relationship with PQ or SUS scores.

(5) Looking at both VE groups, the accuracy for distance estimation scores had a significant positive relationship with SUS Questionnaire scores (modified). For rear-

projection-screen participants, accuracy for orientation and for distance estimation had a significant positive correlation with PQ Total and PQ Natural and PQ Interface Quality subscale scores. For these participants, the results of the retention test had a significant negative correlation with SUS Questionnaire (modified) and PQ Involved/Control subscale scores.

(6) *Visual display had no significant relationship with accuracy of estimating orientation and distance of object locations, but participants using the rear projection screen were significantly more accurate in the initial room placement test than those who only studied the paper-based floor plan. Participants using the rear projection screen were also significantly more accurate than those who used the desktop monitor in the room placement retention test, and both groups were significantly more accurate than participants who only studied the paper-based floor plan.*

[Youngblut 2004 (3)] Youngblut, C. (2004). *Experience of presence in virtual environments* (IDA Document D-2960). Alexandria, VA: Institute for Defense Analyses.

Factors:	Visual display (HMD, desktop monitor).
Computing platform:	700-MHz Pentium III PCs, with NVIDIA GeForce 3 graphics accelerators. Reality by Design, Inc. CHEM-BIO SVS2 software developed using SimStorm. Physiological data captured using Thought Technologies, Inc.'s ProComp+ system.
Visual display:	Proxima 9260 rear projector with 9.5 × 7.5 ft. Da-Lite projection screen, enclosed in curtained-off area.
Audio display:	None.
Tracking:	Head tracking (vertical motion) using InterSense IS-600 Series Precision Motor Tracker.
Navigation:	Using belt-mounted, custom 3D joystick with rear-projection-screen interface, table positioned Microsoft Sidewinder Precision Pro 6 DOF joystick with desktop interface.
Object manipulation:	Using joystick controls.
Virtual world:	A small, Third World town with several open-fronted stores and other buildings along the main streets and some cars on the road. The surrounding area was filled within identical mud huts.
Training:	Participants in each VE group then received 10-min demonstration and practice of the immersive or desktop interface.
Experimental task:	Search for seven stolen missiles in an urban setting while defending against hostile individuals. The missiles were positioned in plain sight. The participant was armed with a gun, controlled by joystick buttons, to defend himself/herself against hostiles. These hostiles were scripted to appear when a participant reached specified locations. Some moved toward the participant; others moved through side streets parallel to, or away from the participant. Each hostile fired on the participant when the participant came into that hostile's FOV. There were a total of 10 hostiles. If the participant was "killed," the visual display blanked for a couple of seconds, and then the participant could resume his search. Six civilians also appeared at pre-scripted points in the scenario. Once a participant had completed his/her search, he/she had to move to an armored vehicle positioned toward the outskirts of the town. 20 min allowed to task.
Participants:	34 student intern employees; 20 males; mean age 22.5 years.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 1.0, 6-item SUS questionnaire, Δskin conductance, Δheart rate.
Person-related meas.:	29-item Witmer-Singer ITQ Version 1.0, gender, experience with video games and 3D computer games, experience with immersive VEs, Ekstrom's cognitive tests (visualization aptitude using Paper Folding test, spatial orientation using Card

		Rotation and Cube Comparison tests, visual memory using Map Memory test, spatial scanning using Map Planning test).
Performance measures:		Mission score calculated using the proportion of missiles found and hostiles killed, adjusted for the number of civilians killed by mistake and the number of times a participant "died."
Findings:	(1)	Desktop-monitor participants gave significantly higher SUS Questionnaire scores (scored in the traditional and modified manner).
	(2)	For HMD participants, PQ Interface Quality subscale had a significant negative correlation with SUS Questionnaire results (traditional). For desktop-monitor participants, PQ Total and all subscales had a significant positive correlation with SUS Questionnaire scores (modified), and PQ Interface Quality subscale had a significant positive relationship with SUS Questionnaire scores (traditional). Δskin conductance had a significant negative correlation with PQ Total and PQ Natural scores. Looking at both VE groups, the two methods of scoring the SUS Questionnaire scores had a significant positive relationship.
	(3)	For HMD participants, VE experience had a significant positive relationship with PQ Natural subscale scores and a significant negative correlation with Δskin conductance. There was a significant positive relationship between computer game experience and Δheart rate, and a significant negative correlation between spatial orientation (card rotations) and PQ Total and PQ Involved/Control subscale scores. For desktop-monitor participants, gender had a significant relationship with SUS Questionnaire scores (modified) and PQ Involved/Control and PQ Natural subscale scores. In all cases, females reported higher levels of presence. ITQ scores, visualization aptitude, spatial orientation (cube comparisons), visual memory, and spatial scanning ability had no relationship with PQ or SUS scores.
	(4)	Desktop-monitor participants showed a significant positive relationship between VE experience and PQ Involved/Control subscale scores; a significant negative correlations between ITQ Total and PQ Total and PQ Interface Quality subscale scores; and significant negative correlations between ITQ Involvement subscale and PQ Total and PQ Involved/Control and PQ Natural subscales and SUS Questionnaire (modified) scores. Gender, experience with computer games, visualization aptitude, spatial orientation, visual memory, and spatial scanning had no relationships with PQ or SUS scores.
	(5)	For desktop-monitor participants, there was a significant positive correlation between mission score and PQ Interface Quality subscale scores. No relationships were found for the SUS Questionnaire, Δskin conductance, or Δheart rate.
	(6)	*Visual display had a no significant relationship with mission score.*

[Youngblut 2002] Youngblut, C., and Perrin, B. M. (2002). Investigating the relationship between presence and task performance in virtual environments. Paper presented at IMAGE 2002 Conference, Scottsdale, AZ, July.

Factors:	Practice with interface (basic 2–3 min, extended additional 30 min).
Computing platform:	SGI Reality Monster. dVise software.
Visual display:	Virtual Research stereoscopic HMD, resolution 640 × 480, refresh rate 30 Hz. Participant standing, free to walk as necessary for task.
Audio display:	Task statements prerecorded using Authorware on PC.
Tracking:	Ascension Technology's Flock of Birds for head and hand tracking.
Navigation:	Based on head movement.
Object manipulation:	3D mouse button used for grasping objects.
Virtual world:	Aircraft hangar with an entire F/A-18 aircraft. Self-representation as virtual hand.
Training:	For basic practice, written description of task and interface, and 2–3 min of familiarization with activities, such as moving to an object and grasping and manipulating it. For extended practice, basic practice plus about 30 min of practice on a task different to that used in the study.

Experimental task:	24-step F/A-18 maintenance procedure involving the removal and replacement of the wing high-level fuel valve. The procedure is performed inside an access area in the wing and involves both physical obstructions (parts that must be removed to get to the fuel valve) and visual obstructions (even after the physically obstructing parts have been removed, several of the fasteners holding the fuel valve cannot be seen through the access door). One practice run of the task in the VE, accompanied by verbal instructions. Training transfer tested on a physical mock-up.
Participants:	40 participants from Boeing staff; 27 males; age range 20 to 64; mean age 40 years. No prior experience with aircraft maintenance.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 1.0, 6-item SUS questionnaire.
Person-related meas.:	29-item Witmer-Singer ITQ Version 1.0, visualization aptitude using Paper Folding test, experience with relevant tools (e.g., fixing cars), age, gender, height, experience with video games and 3D computer games, experience with immersive VEs.
Task-related measures:	Kennedy SSQ, rating of fatigue.
Performance measures:	Paper-and-pencil knowledge test, time to complete task on physical mock-up, count of performance errors while completing training transfer test.

Findings:

(1) Practice with interface had no significant relationship with SUS scores, and a significant positive relationship with PQ Interface subscale.

(2) The only personal characteristic that had a significant correlation with SUS questionnaire scores was the ITQ Focus subscale. This was a positive correlation.

(3) ITQ scores, age, gender, 3D computer game experience, and visualization aptitude had no significant correlations with PQ scores. Video game experience had a significant negative correlation with PQ Involved subscale. VE experience had a significant negative correlation with PQ Total and PQ Involved subscale.

(4) SSQ Total and Fatigue had no significant correlation with SUS questionnaire scores.

(5) SSQ Oculomotor subscale had a significant negative correlation with PQ Total. SSQ Total and Oculomotor subscale had a significant negative correlation with PQ Involved subscale. Fatigue had a significant negative correlation with PQ Interface subscale.

(6) PQ Total and all subscale scores had a significant positive correlation with SUS Questionnaire scores.

(7) SUS Questionnaire and PQ Involved subscale scores had a significant negative correlation with count of performance errors.

(8) Practice had no significant relationship with any performance measure.

(9) Experience with relevant tools and visualization aptitude had a significant positive association with knowledge test scores and a significant negative association with both training transfer tests. Gender had a significant association with both the knowledge test scores and time taken for the training transfer test, with males achieving higher test scores and females taking less time. Video game and 3D computer game experience had a significant negative association on time taken for the transfer test.

(10) SSQ Total and Fatigue had no significant association with any performance measure.

[Zimmons 2003] Zimmons, P., and Panter, A. (2003). The influence of rendering quality on presence and task performance in a virtual environment. *Proceedings of IEEE Virtual Reality 2003,* Los Angeles, USA, March, 293–294.

Factors:	Texture mapping (combinations of high/low texture resolution and high/low lighting quality plus additional condition of black and white grid texture).
Computing Platform:	Rendering with ATI Technologies Radion 8500 with dual video outputs. Lightscape for lighting computations.

Visual display:	Virtual Research V8 HMD, with 640 × 480 pixels per eye.
Auditory display:	None.
Physiological devices:	ProComp+ worn as backpack for heart rate and skin conductance measurement.
Tracking:	3rdTech optical tracking system for head and hand tracking.
Navigation:	Using joystick.
Object manipulation:	Using joystick with trigger to pick up and drop objects.
Virtual world:	2-room virtual world, consisting of a training room and pit room.
Training:	Practice using VE interface in the training room, including picking up and dropping objects on a target.
Experimental task:	Drop four objects on targets in a virtual chasm.
Participants:	55 college-age participants; 25 males. No prior VE experience, no phobia of heights.
Presence measures:	SUS Questionnaire, Δheart rate, Δskin conductance.
Person-related meas.:	Gender, *Guilford-Zimmerman spatial orientation test*.
Task-related measures:	Kennedy SSQ.
Performance meas.:	*Accuracy of dropping balls on targets*.
Findings: (1)	Texture mapping had no significant relationship with any presence measure.
(2)	Gender had no significant relationship with presence.
(3)	*Texture mapping had no significant relationship with task performance.*
(4)	*SSQ scores and height anxiety had no significant correlation with texture mapping but had a significant correlation with gender.*
(5)	*Spatial ability had no significant correlation with task performance but had a significant difference for gender.*

[Znaidi 2006] Znaidi, F., Viaud-Delmon, I., Warusfel, O., and Jouvent, R. (2006). *Towards a cognitive and sensorial model of presence: a study in different virtual sensory conditions*. Poster presented at the 11th Annual CyberTherapy Conference, Gatineau, Quebec, Canada, June.

Factors:	Sensory information (visual environment, auditory/visual environment, audio environment.
Visual display:	HMD.
Tracking:	Head tracking.
Navigation:	Mouse.
Object manipulation:	None.
Virtual world:	Virtual town, where a noise distracter coming from the physical (lab) environment began 5 min after session started.
Experimental task:	Find movie theater, then swing, then count number of bus stops. Sounds played when participant enters an activation area. Large activation areas included ambisonic sound scenes recorded in an urban environment. Small activation areas were binaurally rendered from monophonic sources.
Participants:	9 patients with specific phobias and 10 healthy persons.
Presence measures:	IPQ.
Person-related meas.:	*22-item Cybersickness Scale*.
Findings: (1)	Healthy participants reported significantly more presence than phobic patients in the audio environment.
(2)	*Patients reported significantly more cybersickness in the audio environment than healthy participants. For both groups, cybersickness significantly decreased in the second session.*

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14. ABSTRACT

This report reviews the results of experiments that have examined the sense of spatial presence experienced in virtual environments. It provides guidance about factors that have a good probability of manipulating presence and gives an idea of the scope of experimentation that has been performed. Over 120 experiments are identified, but the analysis focuses on those experiments that have been replicated (more or less) and on factors that have shown consistent results across studies.

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